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September 23-26, 1941

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1940-1941

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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Life Member shall be a member whose service to the Association entitles him to special recognition by the Association.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

	Initiation Fees		*Annual Dues*
Members	$ 3.00	Members	$ 6.00
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This Association has at least eight regular meetings each year, of which five are held in Boston, one in northern New England, one in southern New England, and one, the annual convention, held in September on such date as the Executive Committee may designate.

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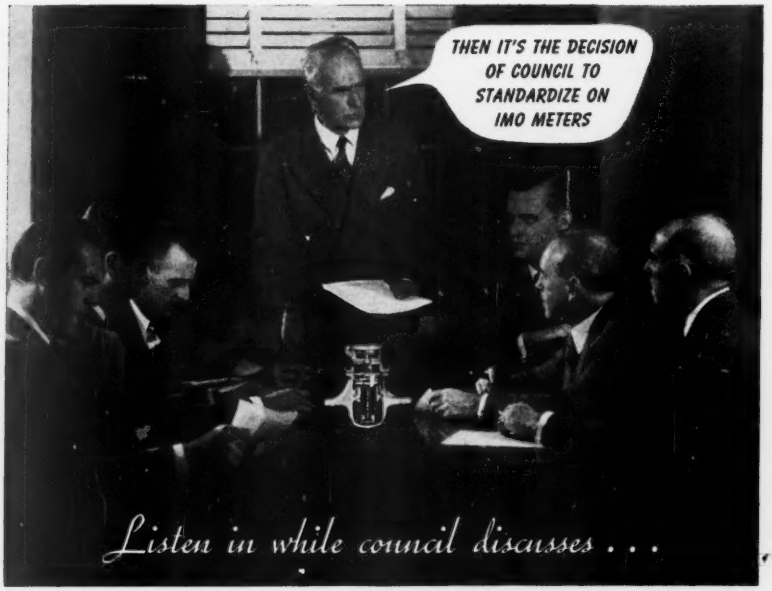

the Pittsburgh IMO Meter

SCENE: Council Meeting, Hometown . . . . . TIME: January 1941

MAYOR HARRINGTON: The next business is the water meter program for this year. I'll ask Superintendent Smith for his recommendations.

WATER SUPERINTENDENT SMITH: Mr. Mayor, I recommend standardizing on the IMO Meter. I've put them to every test and they have proved more accurate and durable than any meter we've ever used.

COUNCILMAN STONE: Is that the meter you put in my house, Smith, when Mrs. Stone was sick and complained about the noise the old meter was making?

SUPERINTENDENT SMITH: Yes, and it was a sample that had already measured 1,000,000 gallons. Before installing it on Mr. Stone's service line, I put it on our prover and it still tested better than the new disc meters we've been buying.

COUNCILMAN GROSS: But is this extreme accuracy necessary? After all, water is cheap.

SUPERINTENDENT SMITH: The thing that sold me on the IMO Meter, Mr. Gross, is its sustained accuracy. We're losing a sizeable part of our expected revenue from meters that, after a few years, either don't record the lower flow rates or only record a portion of them. About a third of the domestic consumption is at flow rates of less than one gallon per minute. With IMO Meters accurately measuring the low flows, I figure to boost our water income enough to pay for these new meters in a very short time.

MAYOR HARRINGTON: Thank you, Mr. Smith. I think you have given us some sound reasons for standardizing on the IMO Meter.

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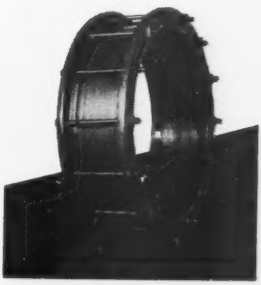

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Photo by Albert Steiger Co.

LELAND G. CARLTON
President of the New England Water Works Association 1940-1941

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ORGANIZED 1882

Vol. LV March, 1941 No. 1

This Association, as a body, is not responsible for the statements or opinions of any of its members

AMERICAN SELECTIVE SERVICE

A Brief Account of Its Historical Background and Description of the Present Law

BY DAVID B. WEDEN*

[*Read December 19, 1940.*]

The obligation to contribute military service in defense of the common safety is as old as the law of self-preservation. Men of all races and wherever found have accepted this obligation as an inherent part of communal existence. In the first chapter of Numbers, the Bible relates that Moses and Aaron registered and classified the Jews and placed 603,550 in Class I. The greatness of Rome was built upon its citizen soldier who furnished his own arms and equipment and served without pay for ten years or longer. The decline of Rome came when its defense was wholly entrusted to professional troops and the citizens lost their skill with arms. In the earliest Anglo-Saxon days every free man was obliged to respond to the summons to arms and to furnish his own equipment and maintain himself in the field at his own expense. Military service was a personal obligation, the obligation of freedom.

The drafting of soldiers in the United States did not begin in 1917 nor even in 1863. The first settlers brought with them the English Militia System, and the grim necessities of pioneer existence strengthened the already recognized obligation of universal military service. The Continental Congress, among its earliest measures for the common defense recommended "to the inhabitants of the United English Colonies that *all* able-bodied effective men between 16 and 50 years of age be formed into companies of militia". The ancient obligation was thus reaffirmed at the very birth of the United States. Manpower procurement in the Revolution and in the War of 1812 was, however, a difficult problem. Volunteers were willing to enlist

*Major, A.G.D., U.S.A., Massachusetts State Headquarters for Selective Service, Boston, Mass.

for short periods to defend their own homes, but objected strongly to being sent out of their particular district. Because the central government lacked power to raise an adequate army, the Revolution dragged out for seven years, during which the Americans employed a total of almost 400,000 men, while the greatest strength of the enemy in any one year (1781) was but 42,000. In the War of 1812, we employed all told, 527,000 men while the enemy never had over 16,500 in the field against us at any one time.

The procurement of manpower during the Civil War was a complete lesson on "how not to do it". In spite of the earlier lessons of the Revolution and the War of 1812, the first efforts to raise an army were the same old methods of short-time drafts on State Militia and by volunteering. Such troops as were raised by these methods were maintained at great expense, until trained, and then claimed their discharge when they were just about ready for effective use.

National Conscription was not introduced until the Spring of 1863. The methods used aroused public resentment so greatly that the authority of the Federal Government was gravely threatened in many of the States which had remained loyally in the Union. It was a coercive factor in a vastly expensive recruiting process—its weight fell wholly on the poor—it nourished vicious forms of corruption. It was begun too late after enthusiasm for the war had died. It aroused bitter hatred and was resisted by riots amounting to serious insurrections. It can perhaps be excused as the measure of a desperate government, but it was about as bad as it could have been.

In one of the most valuable reports ever put in a pigeon hole, Brigadier General Oakes, who as Assistant Provost-Marshal General of Illinois administered the draft in that state, clearly explained in 1866 the faults of the Civil War Draft and made suggestions for better procedure in a future emergency. A full fifty years later, long after he was dead, General Oakes rendered his country a splendid service, for his report was exhumed and its lesson carefully noted in preparing a wise and completely successful conscription.

The Selective Service of 1917, as you all know, was a success. It was successful because it was instituted at the proper time—the beginning—and thus avoided the effect of belated coercion after other methods had failed. The obligation of service was held to be per-

sonal and non-transferable; devices favorable to the rich such as purchased substitution and purchased exemption, were forbidden. Responsibility was dispersed to units of population so small that officials were accessible to the public. The officials were not military men but civilians, well known in their communities. A man's liability and availability for service were decided by his own neighbors. If favoritism crept in, it did so in full view of the community, and no blame was attached to the armed services.

The Selective Training and Service Act of 1940 is based largely on the 1917 law. It provides for the first peace-time draft in the history of our nation. In spite of the long debate before Congress, it had the support of the vast majority of our citizens from the very start. This bill provided in essence that in addition to a Regular Army then being recruited to 375,000 men and a National Guard of some 230,000 men slated for a year's active duty, our army should be increased by 900,000 men. This means an army of approximately a million and a half men in field training by July 1, 1941. The law established the principle that all men between 21 and 36 were equally liable for training and service and that after registration of our manpower 900,000 men should be selected impartially and on the general basis that those most available in the national interest should be selected.

Let me describe briefly the organizational set-up of the system. A National headquarters in charge of a director of selective service is established in Washington. This director is appointed by the President with the approval of the Senate, and is responsible to them for the proper functioning of the system. The governor of each state is responsible for the operation of the law within his state and has set up a headquarters and appointed a state director with various assistants. In most cases, the Adjutant General has been chosen as state director, and the state staffs which previously had made a special study of the subject have been called into federal service to supervise the work. The foundation of the whole system, however, is the local boards, of which there are 173 in Massachusetts. Upon these boards, with their examining physicians and government appeal agents, will fall the duty of classifying and selecting the young men in their own community who are to have the privilege of serving their

country for a year. The members of these boards are well known and respected citizens, who know their community, its problems, and its people. This, in itself, will insure that the actions of these local boards will be fair and just. In addition, the publicity that they are required to give to their actions and decisions will prevent favoritism or discrimination.

Advisory boards, 173 in number, have been organized to assist registrants in preparing their questionnaires. Seven appeal boards, selected mainly from the judiciary, are ready to hear appeals from decisions of local boards if required, and fifteen medical advisory boards, composed of leading specialists will review cases of doubtful medical claims. All told, nearly 5,000 volunteer workers in this state are required to operate the Selective Service System.

The plan of operation embraces three main phases of activity: registration, classification and selection. On October 16, 1940, the first phase—registration—occurred, when more than 16 million men inscribed their names on the roll of those ready to serve their country. There were no riots, no demonstrations of protest, and no disorders. We know of less than 100 cases of outright refusal in the entire country to register. It was a clear demonstration of the soundness and patriotism of our youth. A great national lottery held in Washington on October 29, 1940, determined the order in which these men would be selected for their period of training.

Each local board is now in the process of classifying its registrants on the basis of an eight page questionnaire and such other information as it sees fit to obtain. After classification, each man is placed into one of four general classes:

Class I—available for military service
Class II—deferred because of occupational status
Class III—deferred specifically because of dependents
Class IV—deferred specifically by law or because unfit for military service

Aside from physical unfitness, the two broad bases for deferment are: first, the "necessary man" in the "necessary industry", and, second, the man with dependents. I am sure that the members of this Association are interested in the policies underlying each of these groups of deferments.

During the last war, the basis for occupational deferments or as they were then termed "exemptions", included certain exemptions for entire industries, such as the shipbuilding industry, which was designed to stimulate the building of cargo boats so necessary at that time because of the U-boat campaign. However, this blanket exemption resulted in almost a national scandal with draft dodgers hurrying to become ship riveters, whether they had any such experience or not. The present law states clearly: "No deferment from training and service shall be made in the case of any individual except upon the basis of the status of such individual and no deferment shall be made of individuals by occupational groups or groups of individuals in any plant or institution." The man who is to be deferred because he is needed in his civilian capacity must be one who cannot be replaced satisfactorily because of a shortage in his particular qualifications or skill, and it must be shown that his removal would cause a material loss of effectiveness in his particular activity. The regulations also require for such deferment that the maintenance of the business, agricultural pursuit, or governmental service in which he may be engaged, is necessary to the national health, safety, or interest. Local boards are cautioned to give particular thought in this connection to defense industries.

In viewing this whole question of occupational deferment, it must be recognized clearly that it is not intended that every man with a good job is to be deferred. Fundamentally, Selective Service is designed to procure men to augment our armed forces. It must do this impartially in the national interest. It must disturb as little as possible the economic life of our communities. On the other hand, every man in the age group is liable under the law for training and service, and only those should be deferred who are so greatly needed in their civilian capacity that the national interest requires them to remain at home. A man thus properly deferred is doing his bit for the national defense just as surely as the man in the Army or Navy, and should not be considered any less patriotic.

While local boards bear the brunt of making these individual decisions, the responsible heads of industry and the executive officers of the states and local governments and also the heads of departments of the federal government itself have a very real responsibility to see, so

far as their influence goes, that this provision is fairly and justly exercised. Local boards cannot but be influenced by requests from important employers whether they be in government or in business. All employers and all personnel officers should consider the best interests of the nation and carefully weigh their policy in requesting deferment for employees. They should place themselves mentally in the position of the local boards and only ask deferment for employees when, in both the letter and the spirit of the law itself, they actually believe that the work involved is highly important and that the man engaged in it cannot be replaced within a reasonable time without an adverse effect on some vital phase of the activity. Where these conditions are met, however, it is clearly their duty to submit complete information concerning each such case to the local board having jurisdiction over the man involved.

Public opinion alone can make a law of this type successful, and this is particularly true in peace-time. Public opinion will only continue to support compulsory military training and service wholeheartedly if it is convinced that each man is treated fairly and justly, and that deferments are granted or withheld without fear or favor.

In this connection, I doubt whether employers generally, or the public itself, or even the sixteen million registrants, realize fully how really modest the present program is, or how small a percentage of the total men available will really be inducted for training. Nine hundred thousand, while a large figure in itself, is less than five per cent of those who have registered. Only a part of those employed in any plant or factory are within the age group twenty-one to thirty-six, and only one in twenty on the average of these will have their numbers come up during the coming year. Industry and the economic life of the country generally will not be disrupted by this program.

Deferment for dependency has also been considered from the point of view of the national interest. The Advisory Committee on Selective Service appointed by President Roosevelt, which has carefully considered all of the rules and regulations, came to the conclusion that fundamentally the maintenance of the family as a unit is of great importance to the national well being. The legislative background concerning this problem of deferment for dependency is of real interest. Members of the General Staff of the Army appeared

before the Congressional Committees and stated categorically that they had no desire to induct married men. The early drafts of the legislation provided for deferment for those with dependents when such action appeared advisable, leaving to the President full discretion as to the method of such determination. However, in the final conference report the Congress defined the term "dependent" to include only an individual who is dependent in fact on the registrant for support in a reasonable manner on income earned by the registrant in a business, occupation, or employment.

This clearly limited the right of the regulations to defer for dependency unless the so-called dependents were in fact dependent on the registrant's own earned income. The Selective Service Administration and the Army General Staff believe that within this limitation and under present conditions it is desirable so far as possible to prevent the separation of a father from his children or a husband from his wife and that this conception is definitely in the national interest. Therefore, the regulations read: "Any reasonable doubts in connection with dependency should be resolved in favor of deferment. . . . The local board should be diligent in preventing registrants from evading military service where their status with respect to dependents does not warrant their deferment, but the local board must be equally diligent in making its classification to protect the registrant's dependents."

The next and final step before induction is that of selecting those men classified in Class I-A, as available for immediate service. National headquarters establishes a quota for each state based on its Class I-A registrants and giving credit for the number of men from this state who are already in the armed forces. Massachusetts' tentative quota up to June 30, 1941 is 20,556. The Army, at various intervals, based on its ability to house, clothe, and train men, makes requisition on the state headquarters for such quotas as they require.

State headquarters in turn must break this figure down for the 173 local boards throughout the state, giving each its due credit for men already in service. Each board then fills its quota from its Class I-A list according to order.

This is a very brief description of the work involved, and brings out, I hope, the almost complete dependence upon community endeavor, for the successful operation of selective service.

And now, how about the young man who has been selected for training in the Army. He will receive an education in many things, which, in civilian life, he had never dreamed existed. His physique will be built up and strengthened. The year should prove to be a Great Adventure, to those who make the most of their year in the service. It is my hope and my expectation that the young men selected will come back to their communities better equipped mentally and physically and with a truer realization of the rights of the individual which our democracy guarantees, and also of the equally important obligations, of citizenship. In a word, they will be better Americans.

The popular acceptance of selective service reposes a high trust in those who administer it. If a year from today that popular support has not been shaken, but has rather grown stronger through the coming months, then that trust will have been justified, and the responsibility of the Selective Service Administration and of the Army will have been properly discharged.

ACTION OF MASSACHUSETTS DEPARTMENT OF PUBLIC HEALTH IN THE EMERGENCY PROTECTION OF PUBLIC WATER SUPPLIES

BY ARTHUR D. WESTON*

[*Read January 16, 1941.*]

Communications as form letters have been sent to various water departments of the State of Massachusetts under dates of June 13, 1940, November 27, 1940, and December 23, 1940, with the view to protecting sources of water supply more adequately during the present national emergency.

The communication of June 13 recommended (1) that adequate supervision be provided to prevent trespassing in the vicinity of pumping stations and reservoirs, wells, springs and filter galleries or other sources from which water is taken directly for water supply purposes and (2) that all filters, chlorinating apparatus and other works for purifying or disinfecting the water be adequately maintained and provided with sufficient extra parts, cylinders of chlorine, etc. for emergency use. In that communication the Department also recommended that protection be given to power lines where electric power is the only power available and that consideration be given to the installation of auxiliary power; also that consideration be given to emergency or auxiliary connections with the distributing systems of adjacent public supplies.

In its communication of November 27 the Department of Public Health called attention to the necessity of maintaining careful supervision of all cross-connections, especially check valves between polluted water supplies and the public water supply, and recommended in this connection that the industries be advised of the need for careful supervision of such cross-connections at all times. Relative to improperly protected cross-connections, the Department recommended that all such connections be removed.

The communication of December 23 called the attention of the

*Chief Engineer, Division of Sanitary Engineering.

water departments to action of the Department which revokes all prior authority of boards of water commissioners and others to grant permits for boating, fishing, ice cutting or to send, drive, or put, any animal into, or to enter, or go, into any boat, seaplane or other contrivance upon the water or upon the ice of any body of water from which water is taken *directly* for domestic use. Information which the Department has received from the Federal and State Military Intelligence Bureaus assures the Department that such action is necessary.

Regarding the granting of permits for boating, fishing and ice cutting, it has not been the intention of the Department of Public Health to cause any hardships in this regard, and, where ice houses and other works for ice cutting on direct sources of water supply represent a considerable investment, the Department has already granted permits for continuing the practice of ice cutting, but with the understanding that such ice cutting shall be in accordance with the following conditions that are quoted from a recent letter from the Department:

(1) That no ice be harvested and that no workmen be permitted to approach nearer than 250 feet from the water works intake pipe.

(2) That no animals be driven upon the ice.

(3) That suitable facilities for the reception, collection and disposal of urine and excreta and other wastes of those employed shall be provided, that such facilities shall be equipped with watertight containers, that the contents of such containers shall be removed from the watershed and disposed of in the public sewers under the supervision of the water works superintendent and that expectorating or depositing of any other polluting materials on the surface of the ice or in the water of the pond be prevented.

(4) That all harvesting of ice be under the direct supervision of an authorized representative of the Board of Water and Sewer Commissioners of the town of ———— in accordance with the rules and regulations adopted by this Department under date of ————.

(5) That all water supplied from ———— be adequately chlorinated during the ice harvesting operations and for such additional time thereafter as may later be determined by the Department

of Public Health and that no ice-cutting shall be begun until suitable chlorinating apparatus has been installed and shown to be operating satisfactorily.

(6) That the Department be informed 24 hours in advance of the time when ice-cutting is to be started and that it be advised immediately after ice-cutting has ceased.

It is believed that the Department will continue this practice after careful consideration of each application for a permit. Relative to the granting of permits for boating and fishing on direct sources of water supply, it is obvious that the Department cannot grant permits for this practice until information can be obtained when direct sources of water supply are free from ice, as to the currents through such direct sources of water supply and their relationship to the intake works. Such float tests will be conducted by the Department as rapidly as possible.

Relative to the granting of permits for the landing of seaplanes on direct sources of water supply, the Department is convinced that this is a dangerous practice as such planes may carry with them pollution from other landing places and in any case it is a dangerous practice, especially if permits are granted for boating and fishing. Skating on direct sources of water supply should be prevented.

The Division of Sanitary Engineering recommends that, in all cases where permits have been previously granted for the cutting of ice, application for permits from the Department of Public Health be submitted as early as possible. The Division wishes to assure the water departments that early and careful consideration will be given to these applications.

SUPERVISION OF DAMS AND RESERVOIRS IN CONNECTICUT

BY CLARENCE M. BLAIR*

[*Read September 24, 1940.*]

The failure of any engineering structure that may cause loss of life or damage to property is a matter of public concern. Particularly, the failure of a dam or reservoir focuses the attention of the layman on a type of structure that he inherently fears. The public is entitled to some type of supervision of these structures that impound comparatively large amounts of water, the failure of which would cause loss of life and property damage. How far this supervision by a state agency should go may be a matter of debate. A review of plans by an experienced engineer does not absolutely guarantee that the structure will not fail. Neither does such review relieve the owner of his responsibility in case of failure. But the public is assured by such review that the dam is being constructed by sound engineering design and that all possible safeguards will be taken to produce a safe structure.

The State of Connecticut early recognized the importance of supervising the construction of dams, and has had statutes for at least 70 years providing for inspections of dams. The first law calling for inspection and approval of dams was enacted about 1870. The engineer member of the State Department of Health was commissioned with this responsibility. Later, the appointment of inspectors was made by the Connecticut Railroad Commission. These inspectors were competent engineers, and these statutes safeguarded the public for a number of years.

A new act was passed by the Legislature of 1911, which provided that "the commissioner of rivers, harbors and bridges who is a civil engineer, and one civil engineer residing in each Congressional district, to be appointed by him, shall constitute a board of civil

*Consulting Engineer, New Haven, Conn., and Member of the Connecticut Board of Supervision of Dams and Reservoirs.

engineers who shall have supervision of all dams and reservoirs in any locality where, by the breaking away of same, life and property may be in danger." That this board of civil engineers performed its duties in the public interest is witnessed by the fact that in the long period of years that this board functioned there were no failures of any dams in Connecticut that had been constructed under permits issued by members of this board. The personnel of this board was entirely non-political, and members were selected on the basis of their experience in design and construction of dams and similar structures. The chairman held office for the 28 years that this board functioned. One other member served from 1911 to the date of his death in 1939. In the 28 years of its existence, there were only twelve members who served on this board.

The 1911 statutes limited the power of this board in its duties. They provided that "upon the application in writing of two or more persons or corporations who would suffer loss or damage by the breaking away of any dam or reservoir, a member of the board of civil engineers shall forthwith inspect the same and if in his opinion said dam or reservoir is not sufficiently strong to withstand the action of water under any circumstances which may reasonably be expected to occur, he shall at once serve notice on the person or corporation owning or having the care and control of the same to place said dam or reservoir in a safe condition under the supervision of said engineer". The act further provided that if the engineer found the dam or reservoir to be secure and safe, the expense of said inspection should be paid by the applicants.

Referring to new construction or alterations, the 1911 statutes provided that the plans, specifications and necessary data should be submitted to a member of the board of civil engineers who should examine the ground where the dam or reservoir was to be located and the plans and specifications therefor. If he approved the same, he issued a certificate authorizing construction. If this engineer deemed it necessary he could, before issuing this certificate, call in for consultation and advice the board of civil engineers or any member of said board.

A member of the board was also commissioned to inspect the construction work to the extent necessary in his judgment to deter-

mine whether the structure would be safe and secure. On the completion of the work, he was authorized to issue a certificate approving the same, which certificate was to be recorded by the owner in the land records of the town or towns in which said dam or reservoir was located.

The 1911 statutes provided for appeal by any owner, aggrieved by a decision of a member of said board, to a hearing by said board. Any decision of the board was subject to appeal to any judge of the superior court. Penalties were also provided in these statutes for constructing or owning a dam or reservoir without compliance with the provisions of the act. Rules of this board of civil engineers contained the provision that members of the board, while acting in their official capacity, should not render professional services to owners in connection with the dams and reservoirs concerning which they were officially engaged. And further, "a member of the board who may be employed as designing or construction engineer of a dam, shall, by reason of such employment, be disqualified to act in an official capacity as inspector of such dam, or to issue certificates of approval therefor".

To the writer's knowledge, based on 36 years of engineering experience in Connecticut, and 10 years of membership on this board of civil engineers, the provisions of these statutes were usually well complied with. The act was along sound lines, and it did not needlessly affect the costs to the owners.

Public utilities and other corporations and organizations have usually coöperated fully with the requirements of these statutes. The construction of some small dams by persons not conversant with the statutes, in some cases, resulted in corrections by the board when the construction was discovered. The owner usually coöperated when he was advised of the procedure. In some instances, comparatively few in number, other engineers making plans for dams objected to the requirements of the board, and thus caused the owners to gain the impression that some particular member of the board was increasing the cost of the structures unduly.

The writer remembers one case where an old dam had failed due to inadequate spillway capacity. The engineer for the owner proposed to reconstruct this dam with a spillway of sufficient capacity to

safely pass a runoff equal to the 1936 flood flow. It was argued that the runoff that caused the failure of the dam was the highest in 300 years, therefore the design was safe. It was found that the spillway capacity was very inadequate for predicted flows. A permit was therefore refused by a member of the board, and an appeal was taken to the full board. All possible pressure was brought to bear to obtain this permit. The board was advised by the owner that if he could not proceed with his engineer's plans, the project must be abandoned as the added cost of the structure with the required spillway capacity would be excessive. Nevertheless, the board refused the permit, and the dam was not built. It is interesting to note that two years later there was a very high runoff in this watershed, about double the runoff that caused the failure of the dam. What would have happened to a structure designed by this inexperienced engineer can easily be imagined. In this case, the public was safeguarded by the provision of these statutes, and, of course, the owner was saved a large amount of money by not losing the dam a second time.

The application of these statutes of 1911 for a long period of years developed some points that indicated that a revision would be desirable. There were no provisions that allowed a member of the board of civil engineers to initiate inspection of dams. Only in case of a complaint by two or more persons or corporations who would suffer loss or damage by the breaking away of the dam could the engineer inspect the dam. The provision in the act of 1911 that expenses of such inspection should be paid by the applicants if the dam was found secure also acted as a deterrent of such complaints.

Connecticut history dates back for over 300 years and consequently there are a number of very old structures in this state which might cause large damage and possible loss of life if there were a failure. If these statutes had given the board of civil engineers authority to inspect all dams, and power to condemn unsafe structures, or to limit the height of water impounded by a dam, some of the failures caused by the floods of 1936 and 1938 might have been avoided. One of the primary causes of a number of these failures was the use of flashboards on some of these old dams. With comparatively normal runoffs for a period of years, the tendency was to work in flashboards on the spillways to add to the storage. This

practice of adding flashboards continued, resulting in a serious impairment of the spillway capacity. In 1936, the board of civil engineers adopted a rule that "no permit will be issued permitting flashboards to be added to any dam". However, the board had no power, under the statutes, to order existing flashboards removed, unless complaints were received from owners below the dam.

One weak dam in a watershed, and particularly one located in the upper portions of a watershed, can cause damage to property not only along the stream immediately below the dam, but it may affect every dam downstream. A number of dams that have failed in Connecticut had ample spillway capacity to pass the high flows in the 1936 and 1938 floods, but when a weak dam failed, this wave of water, superimposed on the high runoff in the stream, created a condition that the downstream dams could not withstand, and many failures resulted.

The failures of dams in the 1936 flood caused the governor to inquire what state authority had the power to inspect dams. The limitations of the statutes were called to his attention, and recommendations were made for increasing the statutory powers of the board. At that time a consolidation of state departments was strongly urged by the governor, mainly in the interests of economy. The annual budget of the board of civil engineers was so small that this argument was not valid in this instance. It was proposed, however, that this particular inspection work should be absorbed by another state department. This was strongly opposed by the board of civil engineers and others. The members of the board felt that they were performing a public duty to the state at a nominal cost, and were jealous of the long record of service by its members with no failures of dams supervised under the statutes. A change to another state board, political in nature, would probably react against the best interests of the state. The proposed changes did not prevail.

The floods of September 1938 with very high runoffs brought the subject of dams to the public attention again on account of the number of failures of old dams and resultant large property damage. It was the consensus of opinion that broader powers should be created for state supervision of dams. It was also considered very desirable that this agency should have an office in Hartford, as a

depository for plans and other records, and to act as a clearing house for the work of the board. As a result of excellent coöperation by all concerned, a new act, concerning the supervision of dams and reservoirs, was passed by the Legislature in its 1939 Session. By this act a state board was created "for the supervision of dams, dikes, reservoirs and other similar structures. All such structures, with their appurtenances, without exception and without further definition or enumeration herein, which, by breaking away or otherwise, might endanger life or property, shall be subject to the jurisdiction of this act." The act further provided that this board should consist of the Director of the State Water Commission, who should be chairman of the board, and five appointed members, legal residents of the state for at least five years, licensed to practice professional engineering in Connecticut and especially qualified for their duties by education, training and experience. These members, as provided in the act, are appointed by the governor for five year terms.

This new act gives the board authority and orders it "to investigate and inspect or cause to be inspected all dams or other structures which, in its judgment would, by breaking away, cause loss of life or property damage". Periodic inspections of all such structures are required so as to "reasonably insure that they are maintained in a safe condition". The act further provides that any person, firm or corporation which would suffer loss of life or property by the breaking away of any such structure may petition the board in writing for an inspection. In order to avoid nuisance complaints, a provision is included that the board may require a deposit not to exceed $100.00 to cover such inspection.

The board is further authorized to issue permits for construction after an examination of plans and other documents and an inspection of a proposed site. A member of the board is also authorized to inspect the work to the extent necessary to determine whether the structure will be safe and secure. The board is also authorized to place a competent inspector on the work if circumstances warrant, and the compensation of this inspector shall be shared equally by the state and by the owner. On the completion of the work, a certificate of approval is issued stating that the structure has been constructed to the satisfaction of the board, but subject to such

terms and conditions, if any, as the board may deem necessary for the protection of life and property. This certificate has to be filed by the owner in the land records of the town or towns in which the structure is located.

By this act, the owner is not relieved of any responsibility. The act provides that "nothing in this act, and no order, approval or advice of the board or a member thereof shall relieve the owner or operator of such structure from his legal duties, obligations and liabilities resulting from such ownership or operation. No action for damages sustained through the partial or total failures of any structures or its maintenance, shall be brought or maintained against the state, or member of the board, or the board, or its employees or agents, by reason of supervision of such structures exercised by the board under this act."

Penalties for violations of its provisions are included in the act. The right of appeal is also provided for.

This act was approved June 20, 1939, and appointments to the board were made by Governor Raymond E. Baldwin on July 1, 1939. The five engineers appointed were from different parts of the state, and allocation of territory to each member was based on county boundaries.

This act has now been in effect a little over one year, and has met with public approval. There are a number of advantages to the new organization, particularly in having the office of the State Water Commission as the clearing house for this board, and its able Director as chairman of the board. This has resulted in a closer contact with others of the state official family. Owners of dams have shown a fine spirit of coöperation.

A discussion of some of the problems that have been encountered in the matter of supervision of dams may be interesting. As previously stated, full coöperation is usually given by public utilities, corporations, and some of the owners. Plans for the larger structures are generally prepared by qualified engineers and the designs are, in most cases, acceptable with some minor suggestions. In the case of smaller dams, the owners sometimes do not appreciate the importance of this supervision, and do not prepare adequate plans. In some cases, free advice on plans is sought from members of the board.

If the contemplated structure clearly comes under the provisions of the act, the owners are advised to engage an experienced engineer and present plans for approval.

In recent years, a number of small dams have been constructed in Connecticut for recreational and other purposes. Most of these dams have very limited heights, and are located on small streams with small tributary watersheds. The failure of most of these structures would not damage property or endanger life. These structures do not come under the provisions of the statutes.

In general, it might be stated that dams with less than ½ sq. mile of watershed and/or less than 5 ft. in height are excluded from these provisions.

The procedure of a member of the board, after it has been determined that a proposed structure comes under the provisions of the statutes, and construction plans have been submitted by the owner or his agent, is to make a careful inspection of the site of the proposed dam, and note the rock conditions, etc. A quick reconnaissance of the watershed is also very important in order to classify the type, —fast, medium, or slow runoff. The plans are studied to determine the pertinent facts as to design, etc. The type and capacity of the spillway is one of the most important features to be considered. The determination of the runoff to be provided for at the dam must be given the most careful consideration. Runoffs of similar watersheds must be studied, as well as any data that is available as to this particular watershed.

A number of years ago one member of the old board of civil engineers made a rather extensive study of maximum flood discharges in the northeastern United States. With these data, he proceeded to work out an empirical formula for discharge of watersheds in cubic feet per second per square mile. The formula thus derived was as follows:

$$D = \frac{41{,}600}{M+180} + 20$$

D = discharge in cubic feet per second per square mile
M = area of watershed in square miles.

This formula has been used quite extensively in Connecticut as

a guide for spillway discharges to be provided for in a safe design. Judgment must be used in applying this formula, and certain allowances must be made to suit local conditions. In general, however, the formula has proved its value for a period of years, and many new dams have been constructed with this formula as a guide in the spillway design. After the experiences with the runoffs in the floods of 1936 and 1938, it was found that this formula was adequate for designs where the tributary watershed area was of reasonable size. For small watersheds, however, particularly below 10 sq. miles in area, it was found that the runoffs exceeded the values derived from the formula. The reason for this, the writer believes, is that accurate records of maximum discharges on small watersheds have been very meagre over a period of years, and these discharges have not been accurately noted.

A statement in a paper entitled "Flood Control", in the Transactions of the American Society of Civil Engineers,* is interesting in connection with these small watersheds. Referring to the flood of July 1935 in New York State: "The peak discharges of many small streams with drainage areas of less than 5 sq. miles was incredibly high. There are no gauging stations in the flood area on streams of this size, but subsequent determinations by engineers of the U. S. Geological Survey, using the slope area method, indicate peak discharges of more than 2,000 c.f.s. per sq. mile. It seems probable that some streams draining 1 sq. mile or less, may have had peak discharges of more than 3,000 c.f.s. per sq. mile. . . ." Of course, these values must be used in a reasonable way. The duration of these very high maximum discharges may have been extremely short. Consideration must also be given to the flooded area impounded by a dam in arriving at the proper discharge to provide for. Allowance must be made for errors inherent in this "slope area" method, but these excessive flows do point out clearly that spillways for dams and other structures on small watersheds must be designed more conservatively.

A suggested guide for maximum flood discharges to be provided for in Connecticut is as follows:

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*Vol. 103, p. 617.

Watershed Area sq. mi	Discharge c.f.s. per sq. mile
1	800
2	700
3	600
4	500
5	500
10	400
25	300
50	250

The comparatively few gaugings that are available on small watersheds indicate that these values are reasonably conservative. All factors must be considered in checking up the maximum flood to be provided for by any spillway.

The use of flashboards on spillways is a matter that has been given much consideration by the board. There is no question that many of the failures of dams during the past few years has been caused by the installation of flashboards, with consequent restriction of spillways. There are also some dams where the use of flashboards would not be a hazard. In a few cases, flashboards have been so constructed that they will collapse when the water reaches a certain level above the spillway.

At one of our largest power dams, collapsible steel gates were installed. The experience with these steel gates in recent floods has indicated that at the time of collapse, a large amount of water was released, which sharply accentuated the flood conditions downstream. In a recent court decision, the owners below the dam collected damages from flooding caused by the collapse of these flashboards. The writer's opinion is that flashboards should only be allowed by special permission, after the whole question is studied for a particular structure. Flashboards should only be used when all the data indicates that the safety of the dam is not impaired by their use.

An inventory of all dams in Connecticut has been made, and county maps have been provided for each member of the board to show locations of dams in his territory. As the work of the board continues under the present law, periodic inspections will be made of all dams. The heavy runoffs of 1936 and 1938 have probably eliminated most of the structures that were not adequately designed,

but periodic inspections will be of increasing importance as time goes on. A study of the characteristics of sample watersheds, and the application of the pertinent data obtained to the watersheds of similar area and characteristics will probably be undertaken by the board. The results of this study could well result in economy of design in some cases and better provisions for safety in others.

COOPERATION OF FIRE AND WATER DEPARTMENTS

BY R. C. DENNETT*

[*Read September 27, 1940.*]

In fire fighting there are two elements, two forces, either of which alone is of little value, but with each of good strength, properly coördinated and working together, they can control and extinguish almost any fire under normal conditions. They are, in any city, the water supply and the fire department. It may seem to most of us that to say that there should be full coöperation between the two is axiomatic, that there just naturally is such coöperation. This is true in many cases, but some features are sometimes overlooked and improvements can often be made. Let us discuss some of them.

Maps. In order that the fire chief may make full and intelligent use of the water supply, there are certain things that he should know and certain information that should be furnished to him. A map should be provided showing mains and hydrants. In large cities, it is probably best to have one map showing 12-in. and larger arteries for the entire system and another showing all mains and hydrants in that part of the city in which the company operates on first or second alarms. The map must be plain and easily understandable. It should show the main to which each hydrant connects, as in some cases, where there are two mains in the same street, some hydrants are connected to the smaller main and there may be a substantial difference in the amounts of water available from hydrants that are near together. The size of the hydrant should be shown, as many hydrants are too small for present fire apparatus. Thirty years ago steam fire engines were in use, and generally only a single stream would be taken from an engine; now 750-g.p.m. or 1000-g.pm. and even larger pumpers are used, and often the second company coming in will place a pumper ready for use, at a more distant hydrant, but will utilize hose for additional line from the nearer pumper, thus using it to its full capacity. Thirty years ago mains were installed

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to meet the old conditions; now there is likely to be greater concentration of pumpers close to the fire, and where 4-in. and 6-in. pipe was considered adequate, now 6-in. pipe is the minimum for proper supply with an increasing tendency to the use of 8-in. pipe as a minimum.

Fire-flow Tests. The map will give the fire department a basic idea of how much of a supply they may expect at any locality. But it is important to go even further than this. By means of fire-flow tests, more definite knowledge can be obtained. In a number of cities, these tests are made periodically primarily for the benefit of the water department to locate points that need strengthening. In Chicago, the water department is continually engaged in making studies and tests of the adequacy of fire-flow throughout the city; some 5,000 tests have been made at about 3,000 locations, and, in practically all cases where weaknesses have been found, mains have been laid to correct the condition. Similar work has been done in New York and Detroit. These tests, especially in smaller cities, can be made in coöperation with the chief of the fire department, or at least the information obtained can be made available to him. These tests are of value on the system as it already exists and are of special benefit for new construction. A new manufacturing plant, for example, is to be built; water mains may already exist in the locality, or new ones are to be laid. The fire chief would know how many engines he would use in case of a bad fire in the plant and how he would want them located. A test will show whether or not adequate supply is available. If not, additional mains can be laid and hydrants installed and another test made. Or if no mains are in existence, the fire chief's ideas as to quantity of water required will be a valuable guide. The same thing applies where structural conditions have changed. A section may have been composed of small, or moderate sized dwellings; then an apartment house is built, and quickly, helped by the zoning laws, the district becomes an apartment house section. And now the requirements for fire protection, and perhaps for domestic supply, have largely increased. The former 6-in. mains, with a hydrant at each corner, have become inadequate. The fire chief should have a good idea of the number of pumpers he would use for a serious fire, and he may consider outside aid as well as his own de-

partment; a flow test will show how much is now available. It may not in every case be possible to meet the full requirements at once, but at least the chief will know what he may count on in case of a fire.

Hydrant Marking. In order to give the fire department some idea of what to expect as to quantity available from a hydrant, various methods of marking have been devised. In some cities the size of mains supplying the hydrant and the pressure are marked on the hydrant; in others all hydrants supplied by 4-in. pipe are painted in distinctive color; in still others the next to the last hydrant on each dead end is marked so that the fire department may know that only one more hydrant lies beyond. The plan most used, and recommended by the water works association, is to mark each hydrant as belonging to a certain class: delivering less than 500 g.p.m., between 500 and 1,000 g.p.m., and flow over 1,000 g.p.m. This marking supplies valuable information, but as additional hydrants are used the quantities obtained from each hydrant will be reduced, perhaps seriously. For purposes of more adequate classification, therefore, the flows from groups of hydrants are more dependable than from one hydrant flowing alone.

Hydrant Location. Of course it is generally recognized that the fire chief should be consulted as to the location of new hydrants or extensions, or where the character of a district changes as to construction so that larger quantities of water are required for proper protection. It is also general practice to notify the fire department when hydrants are out of service for any reason; this should also include any changes temporary or permanent, that will affect the pressure or supply in any section of the city. This should apply to increases of supply and pressure, as well as adverse effects. Fire departments today are vitally interested in the protection furnished by automatic sprinkler systems; decreases in pressure affect the efficiency of these systems.

Fires. Another important coöperative feature is the notification of the water department of all fires, and the response of some responsible employee of the department, at least to second alarms, equipped to coöperate with the fire department in any way needed. And there are numerous ways in which this coöperation can be effective. There is always the possibility of a broken hydrant, or even a broken

main, which should be shut off, and there are often cases where large services should be shut off, generally after the fire has passed, but of value in reducing waste. Where there is more than one pressure zone, additional supply can often be obtained by opening one or more valves between the services. In sections that are supplied through regulating valves, it may be desirable to change the settings of valves, or even to open a by-pass. It may be advisable to shut off some heavy uses of water for the duration of a fire, or to sound some special signal to provide for the restriction of lawn sprinkling. The sounding of fire alarms at the pumping station is important if it is necessary to start additional pumps in order to hold the pressure under the increased draft.

Pressure Gages. A feature of importance both to the water department and the fire department is the installation of recording pressure gages at important points in the system; at least in the mercantile section and at the pumping station. There can be no question then as to what the pressure was at any particular time. Sometimes the charge of lack of pressure at a fire is made, though seldom by the fire department unless justified, but often by an unqualified by-stander, and in these cases a record of the pressure is a valuable thing to have, especially for the water department. In any water system, a study of the water planes is often well worth while. The pressure on each hydrant in the city, reduced to feet and added to the elevation of the hydrant will often yield valuable information. It will indicate the points of high consumption, even points where serious leaks exist. As an aid in this study, if recording gages cannot be installed in each fire station the fire chief can be expected to coöperate to the extent of permitting the installation of an ordinary pressure gage in each fire station and arranging that a fireman read the gage and record the pressure every hour.

Emergencies. Sometimes the fire department can be used to good advantage in an emergency. The pumping out of cellars by a fire department pumper is often resorted to; in this case reserve equipment should be used, as there is likelihood of damage to the pump. Often a pumper may be used to pump from a lower to a higher pressure zone, around a check valve or booster pump, where two hydrants are available, close together, one on each zone. Recently,

at Buffalo, a break occurred in a large main at the pumping station; the station was quickly flooded and put out of service. It was necessary to operate by hand a number of large valves; in order to provide immediately men enough for this work the fire department was called upon, and the combined force was able to do the job more quickly than if the immediately available force of the water department had been used alone.

Hurricanes and floods often cause conditions where coöperation between fire departments and water departments can be of great value. A case in New England is much to the point. A flood had crippled the water supply of a small city, and it seemed that the elevated storage would soon be exhausted, leaving the city without water; an outlying section of the distribution system was close to that of a larger city in which the supply had not been affected; hydrants on the two systems were only a few hundred feet apart. The larger city was called upon for help; the fire chief was contacted by the water district, a pumper was provided to pump from one hydrant to another, and a measure of supply was made available during this trying period.

We have tried to cover the more important points of valuable coöperation that must not be considered one-sided. There are others that will doubtless occur to the water superintendents who read this paper.

ACTIVITIES OF THE WORK PROJECTS ADMINISTRATION IN WATER SUPPLY AND DISTRIBUTION

BY J. P. HALLIHAN*

[*Read September 24, 1940.*]

On June 30, 1940, the Work Projects Administration completed five years of operations under the works programs authorized under the Emergency Relief Acts of 1935 to 1939, inclusive. In that period, the expenditure of Federal and sponsor funds on all construction projects assisted by the Work Projects Administration totalled $7,540,849,000, of which approximately 6.81% or $513,536,000 was expended on projects involving improvement of water supply and distribution and water conservation, in the proportions of 78.9% in Federal funds and 21.1% in sponsor funds. (The present program requires a sponsor's contribution of not less than 25%.) New water mains to the extent of 9,613 miles were installed and 2,750 miles of mains reconstructed.

Water is the indispensable element of existence in every community. The purer and the more ample the supply, the more livable the community becomes. Although the volume of employment created is small in comparison with other types of projects, the development, conservation, and purification of water supplies has always held priority in the projects included in the works program of the Work Projects Administration, searching for the means of employment of relief labor that would produce the most permanent benefits to the community and the Nation.

No question has ever been raised as to the suitability of water supply projects for expenditure of relief funds belonging to the whole Nation. Yet in the consideration of such projects it has been necessary to establish certain fairly definite criteria, and the limitations of available labor and material resources have frequently made it impracticable for the Work Projects Administration to render the assistance required on otherwise worthy projects. The most important

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criterion has been that the projects undertaken should have engineering integrity. In this the Work Projects Administration has been materially assisted by the fact that the water departments of most cities are equipped with competent engineering staffs and are not usually restricted in securing consulting advice on special problems.

The Work Projects Administration does not initiate or design projects. That responsibility belongs wholly to the sponsors, but the Work Projects Administration may decline to accept, for its works program, plans that are not in accord with sound engineering practice and may make suggestions for revision where it appears necessary. Most acceptable are those projects that are steps in the execution of a general plan which envisions the future as well as the present needs of the communities concerned.

In normal times, the financing of the water supply needs of a community offers no great difficulty. Rates are usually adjusted with sufficient margin over operation costs to enable creation of reserves to cover financing charges for increases in plant required to meet the normal needs of a growing community. Since 1930, owing to dwindling tax revenues, the necessity of using the available bonding margin for emergency relief, and the reluctance of voters to approve new bond issues, many municipalities have found it necessary, however, to defer or greatly curtail betterments long overdue. The assistance available from the Work Projects Administration since 1935 in the form of relief labor and some contribution in equipment and materials has been of great advantage to such distressed cities, enabling them to carry on their most necessary improvements.

This assistance has been rendered over the whole territory of the United States and its Island possessions. The projects covered are of a very wide range, embracing complete water supply and distribution systems for small communities formerly dependent on individual wells, purification plants for water supplies that were threatened with pollution, rehabilitation of inefficient distribution systems, and construction of storage reservoirs.

It is not unusual for small villages and towns to find themselves faced with a serious health problem by reason of loss of ground water supply. A typical instance, where a village of 3000 population was paying five cents a gallon for raw water hauled from a stream, is in

Hallock, Minnesota, where by the combined efforts of the state relief agency, the village and the Work Projects Administration, a small storage reservoir, purification plant and distribution system, with ample capacity for present and future needs, was installed at a total cost of $83,000. This is an insignificant item in comparison with the $5,720,000 expended by the Work Projects Administration in assisting to create an ample water supply for the special use of the steel plants and other industries in the City of Birmingham, Alabama, to ensure its industrial permanence. Both were highly useful and highly necessary. The details of the Birmingham project which included a rockfill dam 144 ft. high, financed by a loan and grant from the Public Works Administration, have already been presented to the American Water Works Association in the *Journal* of January 1938, by A. Clinton Decker, Member of the Engineering Commission responsible for the design. It is enough to recall that the part of this work contributed by the Work Projects Administration involved the clearing of the flooded area of the impounding reservoir, excavation of the dam site, building an earth dam for a distribution reservoir, laying 28 miles of the 44 miles of distribution mains from 16 to 60 in. in diameter, a chemical adjustment plant and all the service lines, using 4500 relief laborers working in two shifts and contributing substantially to the cost of the materials.

The kind of projects assisted by the Work Projects Administration run the whole gamut of variety between the two extremes noted. Typical of rehabilitation projects is the replacement of the old water-mains of Buffalo, started in November 1935 and not yet fully completed. The heavy relief load in Chicago permitted the development of a plan for reconstruction of the distribution system in Chicago in which the Work Projects Administration participates with relief labor and materials to add to the sponsor's contribution of 24% on a project estimated to cost $10,850,000. An outstanding water softening project is that in Lansing, Mich., where a plant with a capacity of 4.8 m.g.d. is making life easier for the housewives while effecting a saving in costs of $150,000 per year.

In the drought season of 1934, the Kansas City, Mo., water plant was obliged to supply the needs of a great area of surrounding territory. Fire hydrants on all highways leading into the city were

manned for 16 hours a day, and water was given free to anyone bringing a container up to a 500-gal. tank truck. For a time, water was pumped into a newly constructed oil pipe line and distributed to communities in the neighboring state of Iowa. Under subsequent legislation, permitting the formation of water districts, six districts were able to supply their own needs through assistance from the Work Projects Administration in the amount of $324,000, as a part of the total of $5,098,000 being expended in addition to sponsor funds of $1,218,000 in expansion of the Kansas City plant to serve the Metropolitan Area.

Interesting problems were encountered in the thorough rehabilitation of the filter plants of the City of Philadelphia, which, with improvements to the distribution system, will require an expenditure of $5,030,000 in Federal funds and $1,500,000 in sponsor funds. A feature common to all these projects, wherever they were located in the 3070 counties of the United States and of whatever magnitude, was that the work was required to be performed with the labor certified as in need and employable by the local welfare authorities. It was raw, untrained, its capacity unknown, its only asset the will to work and the ability to do a class of work for which the demand had vanished. It had to be sorted, tested, disciplined, trained to the use of unfamiliar tools, work and safety habits developed, and out of its ranks had to come the foremen to direct its operations and to mould it into an efficient construction force. Projects had to be found or developed that would most fully utilize the types of skills available in each community. This was a job requiring superintendents and key men of experience, skill and unlimited patience. Foreman training schools were set up in the larger communities to develop the promising talent, and they have rendered effective aid in the training process. The field of operations of relief workers is limited to their own communities or within convenient transportation beyond it. This consideration has demanded close coöperation between community authorities and the Work Projects Administraton in planning ahead for public works required to absorb the relief load, and the diversified employment has had the beneficial result of making available to reviving industry a pool of labor with broad experience in many types of work.

The necessity of using hand labor wherever economically possible had the effect of lengthening the construction period on many jobs beyond the time in which the work might have been performed through organizations unrestricted as to selection of labor or use of equipment, but it has had no bearing on the requirement of turning out a finished job, which has been met to the satisfaction of the sponsors.

Public Works for February 1936, presented data received from water works superintendents in 68 cities in 29 states on the complete cost of 6-in. cast-iron pipe in place laid with relief labor. The opinion from one water commissioner from a representative city was that it cost about one-third more to do construction work with relief labor than with selected men. A similar analysis at this time would no doubt reflect the improvements in training and supervision that have since been effected. The technical talent found on the relief rolls has been made available to water works authorities in many cities in engineering surveys and analyses of operating performance. Some of these surveys have been found to be very productive. On such a survey to determine the operating losses in the water distribution system, sponsored by the City of New York in 1935, more than 20,000 leaks in water mains were discovered of which 9000 were repaired, effecting a saving of 3,622,000 g.p.d.

There has been general activity throughout the New England territory since 1935 in making provision for increased water supply and storage, a higher degree of purification, and extension of distribution lines over greater service areas. Almost all of this work has been aided by the Work Projects Administration through furnishing the labor required from the relief rolls and in substantial contributions to materials and equipment. The work has been executed in conformity with the plans furnished by the water works engineers and in most cases under their field supervision. The finished jobs have received a high rating from the sponsors, and the Work Projects Administration is particularly pleased with the quality of performance by relief labor on projects of such basic importance to the communities concerned.

The volume of work accomplished in the New England region is rather impressive. The storage capacity in tanks has been increased by 28,400,000 gal. in new construction, and additions and betterments

have extended the life of facilities of a volume of more than 2,000,000,000 gal. There have been added 7,800,000 gal. to the daily capacity of treatment plants in addition to improvements to existing plants. The water distribution systems have been expanded by 589 miles and, by the construction of 29 new dams and the reconstruction and improvement of 44 old dams, the capacity of flood-water storage has been increased by 47,600 acre-feet. The total cost of the work completed and still in progress amounts to $36,598,000 toward which the sponsors appropriated $7,732,000 and the Work Projects Administration contributed $28,666,000.

Projects of outstanding importance have been developed in the larger cities of New England where the need of employment was most acute. In Portland, Me., the Work Projects Administration contributed $352,000 to seven projects. In Montpelier, Vt., $34,480 was contributed to four projects. In Manchester, N. H., the Work Projects Administration was called upon to furnish $1,496,100 on eighteen different projects. On nine projects in the Metropolitan Area of Boston, Mass., the Work Projects Administration contributed $2,887,360. Waterbury, Conn., required assistance in the amount of $467,300 by the Work Projects Administration on eleven projects. Providence, R. I., secured the aid of the Work Projects Administration to the extent of $1,401,000 on three projects.

The mere recital of the number of projects and the amount of money expended conveys a very inadequate idea of the community benefit derived from the work accomplished. In many cases, the need for improved water supply and distribution facilities had been held imperative for many years but could not be undertaken by the communities by reason of their restricted financial resources. This handicap was in evidence in numbers of small communities throughout the New England region desperately in need of a treated water supply to replace a supply from wells that had become contaminated. Combination of a cluster of such communities into a single water district enabled them to pool their funds and obtain facilities through cooperation with their neighbors and the Work Projects Administration that were beyond their reach as individual communities. This arrangement was particularly useful in resort towns where the summer population required services that considerably exceeded those of the perma-

nent winter population. In these cases the necessity of finding useful work for those long unemployed resulted in a double measure of benefit to the community by the creation of an asset of permanent value and the elimination of a menace to public health.

Nor is it possible to show how difficult problems of construction were overcome through the willing effort of the supervisory engineers and of labor that came on the work almost wholly untrained and left behind a perfectly finished job in evidence of their latent adaptability and inherent courage in the face of misfortune.

Discussion

D. M. Sullivan.* The remarks of Mr. Hallihan forcibly bring to my mind the contrast between the way work was done with welfare forces and other relief agencies, previous to the enactment of the Emergency Relief Acts of 1935, creating the Work Projects Administration. Now it is possible to plan work for the present, as well as the future, with some degree of certainty that an attempt at least will be made to carry the work forward.

In 1929, a general plan of improvements to the distribution system of the Boston Water Department was drawn up by the Engineering Division of the department. This plan took in the present needs of the community as well as its future needs. The work to be performed was to be financed from the revenue obtained from the sale of water, and it was anticipated that there would be available approximately $300,000 yearly. In 1931, it became evident that there would be a falling off in the receipts from the sale of water, so that the general plan was more or less curtailed for the reason that the anticipated $300,000 surplus had dwindled to a point where the department, instead of having a surplus, was faced with a possible deficit. In 1932, the laboring force of the department was increased by the addition of some 200 men who were on the relief rolls of the Welfare Department of the city and were compelled to report for work one, two, or three days a week, according to the amount of money they were receiving from the city.

Following the general plan of 1929, the relief workers were as-

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signed to excavating trenches both for extending and relaying of 8-in. and 12-in. water pipe, with the skilled members of the Department's laboring forces assigned to the work of laying the pipes under the general supervisory forces. For the next three years, small improvements were made to the water system by relief workers and federal agencies having the alphabetical symbols of C.W.A., and E.R.A., but no great amount of work was accomplished, and possibly an average of two or three miles of water pipe was laid as contrasted with an average of 6 to 8 miles during previous years.

With the authorization of the W.P.A. under the Emergency Relief Acts of 1935, an elaborate program of public works improvements was drawn up by the engineers of the City of Boston. Improvements to the water system were included in the program, and a blanket project was submitted to the W.P.A. calling for the laying and relaying of water mains of all sizes in various sections of the city to improve the fire protection of the districts. The project was approved for the expenditure of $2,000,000 with about 33 1/3% sponsor's contribution. Later, approval was received for an additional expenditure of $2,000,000 with a similar contribution from the sponsor.

During the past five years, all of the major improvements to the distribution system of the Water Department of the City of Boston have been made in coöperation with the Work Projects Administration. The Department was fortunate in having a competent engineering staff at its disposal and was in a position to present to the W.P.A., for approval, worth while work calling for the replacement of old and small-size water mains by new and larger mains, and for the extension of main pipe lines into newly developed territory where the distribution system was not amply reinforced. The W.P.A. placed in the field a supervisory staff consisting of a field engineer, supervisor engineer, field auditor, and general supervisor with a supervisor at each location where work was being performed. The Water Department insisted that its own trained engineers and inspectors would supervise the operation of gates, hydrants, and the laying of all water pipes and fixtures. This arrangement has worked to the advantage both to the city and the W.P.A.

Labor was supplied to the W.P.A. from relief rolls, and there appeared on the job all types and kinds of labor. The more intelligent

men were grouped and trained by our inspectors and engineers to be pipe layers and calkers, and after serving an apprenticeship were recommended to the W.P.A. for positions in the skilled classes. During the first year, I think I can say without fear of contradiction, both the water department and the W.P.A. were feeling their way along. Only the laying of smaller sizes of pipes was attempted, and all work performed by W.P.A. was given rigid inspection by the Department's trained inspectors and engineers. However, as the forces became more familiar with the work to be performed, larger sizes of cast-iron pipes were relaid.

During the past year, the W.P.A. removed two old cast-iron water mains, 30-in. and 36-in. in diameter, and laid about three miles of 48-in. steel water main in its place, serving as a main feeder to the down-town section of the city. The pipe line was laid under one of the main arteries of the city, parallel to an electric car line, with the trolley cars running at the rate of one car every four minutes. The first 2000 ft. were excavated and trenches braced by the W.P.A., with the city engaging the services of a contractor to remove the old pipe and lay, rivet, and test the new line. The next section, approximately 3000 ft. in length, was designed so that the sections of pipe were connected with mechanical couplings. The W.P.A. excavated, removed the old pipe, laid the new pipe in place and connected the sections together; in short, the entire work was performed by the W.P.A. forces. The remainder of the work was performed entirely by the W.P.A. forces with the exception of the actual work of driving the rivets that connect the sections of pipe together.

This project, performed by the W.P.A. forces, was a most difficult task. The forces engaged in its construction were, a few years ago, wholly untrained. Today, they have a project completed, of lasting benefit to the community and a credit to the organization that sponsored them. The sponsor is not relieved of his responsibility once a project is approved. As there are rules to be followed in every game, so are there rules to be followed in conducting a W.P.A. project. The sponsor must contribute at least 25% of the cost of the project and the Government will supply the remaining 75%. Forms must be made out and signed by the sponsor's agent twice a month, showing the sponsor's contribution. This is an improvement over the old

method of sponsor's contribution. Formerly, the sponsor was rarely ever in a position to know that he was receiving proper credits for the labor and materials furnished.

The Government will agree to supply materials at a rate not to exceed $6.00 for each man-month worked. During the progress of the work, enough money is allocated to the state administration, to carry the project along for only a month at a time; consequently, a job carrying 200 laborers today, may on the morrow find the personnel cut considerably, and a few days or a week later the personnel will reappear as mysteriously as they disappeared. This is disconcerting at times, especially when one is laying water pipes in a busy thoroughfare and finds oneself with a long stretch of street opened ahead, with no one working, and the abutting property owners asking why?

In addition to the W.P.A. participating in a project performed entirely by force acount, the sponsor may also have work performed by the contract method with the W.P.A. participating. The project must be approved by the W.P.A. in the usual manner. The sponsor may then advertise a contract, with contractors submitting a proposal for that part of the work ordinarily assumed by the sponsor, such as supervision, materials, and equipment, the W.P.A. on its part furnishing certain types of labor which, of course, will be expressly stated in the contract. A contract with W.P.A. participating, is now in progress in Boston, the sponsor being the Metropolitan District Commission of the State of Massachusetts.

During the period that the W.P.A. has been in existence, the Water Department of Boston, in coöperation with the Work Projects Administration, has laid, including gates, hydrants and other appurtenances, approximately:

13,700 linear feet of 48-in. steel water pipe
5,000 linear feet of 42-in. steel water pipe
166,400 linear feet of 4-in. to 24-in. cast-iron water pipe.

185,117 linear feet or 35.06 miles.

To perform this work there were 33,600 man-months worked, or an average of 500 men per month. The total amount spent was $3,346,939, of which the sponsor's contribution was $785,118, or about 23.4%, with the remaining 76.6% being supplied by the W.P.A.

These figures compare very favorably, I think, with the figures given by Mr. Hallihan for the country as a whole, namely, 78.9% Federal contribution and 21.1% sponsor contribution.

SAMUEL M. ELLSWORTH.* Probably most of the members of the New England Water Works Association have been concerned directly or indirectly with W.P.A. water projects during these last few years. It is safe to say that the majority of the publicly-owned waterworks in New England can point to improvements either in distribution systems or supply works that have been carried out by W.P.A. labor. To some who have had experience with such water projects, the benefits may be over-shadowed by the difficulties experienced in carrying on work of this kind. They may recall the seemingly endless revisions to project applications, the long delays in having men assigned to projects that were otherwise ready for operation, the feeling of rebellion in having a project shut down at a critical point because of time-control regulations, or the criticisms and jibes of fellow townsmen when progress was slow. Because of these difficulties, some will be unable to see any good in the W.P.A. There are others, however, who will take a broader view and admit that the benefits are worth all the difficulties surrounding such projects.

Mr. Hallihan appraises the accomplishments of the W.P.A. in the field of water supply both in terms of dollars and cents, and in terms of miles of water mains laid or new supplies constructed. By either yardstick, the accomplishments in this field by W.P.A. labor are of staggering proportions. The laying or reconstruction of over 12,000 miles of water mains, chiefly by hand labor, is something to boast about, although the writer is not so sure that the same can be said about the expenditure of more than half a billion dollars on water projects, at least from the standpoint of the waterworks superintendent or the waterworks engineer. We should remember that the primary purpose of the W.P.A. was, and still purports to be, the relief of unemployment. In accomplishing this purpose, there has been a by-product in the form of useful public works. If we are to measure the accomplishments in terms of dollars and cents, then we must think in terms of unemployment relief rather than economic value of the

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works that have been constructed. To attempt to justify most W.P.A. projects from any other standpoint than work relief, is to ignore the experience record of the last five years.

It might be of interest to cite an example bearing on the engineering economics of W.P.A. projects. I have in mind a small waterworks where the distribution system was constructed by W.P.A. labor. In general, the project was well-managed and no unusual difficulties were encountered. The labor furnished by the W.P.A. was better than average, leaning on shovels being the exception rather than the rule. This project was carried on with a minimum of mechanical equipment, such equipment being limited chiefly to trucks and air compressors. It was obvious in the fall of 1939 that the project would go over into the winter unless it could be speeded up in some way. Rather than pay rentals on air compressors to handle frozen ground during the winter, it was decided to hire an excavator and attempt to finish the work before cold weather set in. An excavator was rented at a cost of $5.50 an hour, including the operator. Ground conditions were such that from 500 to 600 ft. of 6-ft. trench could be excavated in an 8-hour day. On this basis, excavation cost 17c per cu. yd.

The cost of the same kind of excavation by hand during the summer months had amounted to $2.10 per cu. yd. During the preceding winter the average cost of excavation during the four winter months had been $5.08 per cu. yd. Comparing these prices with the unit cost of 17 cents per cu. yd. for machine excavation, the saving ranged from $1.93 per cu. yd. for summer conditions to $4.91 for winter conditions. Since the use of the excavator in the case described made winter excavation unnecessary, the latter amount is most significant. On this basis a saving of 97% was effected by the use of the excavator.

Now, what does this mean from the standpoint of the W.P.A. worker? Taking the prevailing wage rates on this project, a unit price for hand excavation of $2.10 per cu. yd. and a force of twenty-five men, one foreman and a quarter of the time of a supervisor, it would require five 8-hour days to do the work done by the trenching machine in one day. The men would receive an average wage for these five days of $19.80. With the excavator doing the work the men could have been paid $18.30 for not working, all without affecting

the cost of excavation. In this case then the Federal Government was spending $19.80 per man for unemployment relief and realizing a return, based on true economic values, of $1.50 per man. The latter represents the by-product previously mentioned. Of course if we consider the sponsor community by itself, the picture is not quite so weird. Nevertheless this simple example should teach a lesson: namely, that we are wasting national wealth, whether in terms of idle machinery or man power, when men are used to do work that can be done much cheaper by machines.

The question immediately arises as to how public works construction is to be carried on for unemployment relief without entailing too great an economic loss. In the example just cited it is evident that machine excavation should have been carried on whenever conditions permitted. Even with the Federal Government paying the entire rental, the overall economic loss would have been less. Actually the writer is of the opinion that the community should have been compelled to contribute a large portion of the cost of equipment rental, and that this should have been a condition for the approval of the project by the W.P.A. authorities. Obviously, fewer men would be employed on such a project, and other work would have to be found for them if the same degree of unemployment relief were to be given. Expenditures for equipment would thus entail extra expense, either by the sponsor or the Federal Government, but this would be preferable in the writer's opinion to the waste of national wealth that comes from the squandering of labor.

Again the writer wants to emphasize the point he is trying to make: that the W.P.A., as constituted, is for unemployment relief and that its existence can be justified for no other reason. It has served this purpose well. Considering the large scope of its activities and the difficulties of adjusting Federal regulations to meet the problems of local government, those in administrative positions have done a praiseworthy job. As waterworks men, we should not overlook the fact that water projects have been and continue to be given a preferential place on the W.P.A. program.

EFFECT OF 1939 DROUGHT ON WATER SUPPLY PROGRESS IN NEW JERSEY

BY CHARLES H. CAPEN*

[*Read September 26, 1940.*]

Droughts are not a new occurrence. Records in ancient hieroglyphics give ample evidence of this. Usually, however, just as little preventive medicine is applied to droughts as to floods. Because of the greater range in drought variations, or perhaps we may more properly say rainfall variations, in the West, the subject has received much more attention there than in the East. The drought that affected the northern part of New Jersey and most of central New York in 1939, however, reached such proportions that its profound effect on water supplies and future planning for them is worthy of record.

Starting early in April, 1939, a dry period began that was not broken until the middle of January, 1940. At least this was true of the area just mentioned. Even in January, the relief was somewhat brief in extent. The real break did not come until the middle of February, and it was not until March that indications were clear that the spell had been finally abated. Comparing this with other years in New Jersey, it is found that the volume of rainfall and runoff between April, 1939 and January, 1940, was strikingly similar to that of April, 1900 to January, 1901. In 1901, however, the drought continued until the middle of March. Had such a condition been repeated, part of New Jersey would have suffered the worst water famine in its history.

To show how peculiar this drought was to a given area, it must be pointed out that a hurricane of considerable extent visited the seacoast of New Jersey on August 19, 1939, and caused high precipitation over the entire southern part of the state. The maximum precipitation was recorded at Tuckerton, where more than 15 in. of rain fell in 48 hours. Scarcely any of the large surface watersheds

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in the northern part of the state benefited materially by this storm, although the catchment area of the Hackensack Water Company, which lies largely within a few miles of tidewater, showed more run-off proportionately than did the others. In some parts of the state less than 2 in. of rain fell and much of this was mostly absorbed by the already dry ground.

The first supply to encounter difficulties was that of the Commonwealth Water Company, but this was due primarily to extremely high domestic consumption, early in the summer when lawn sprinkling and other uses were at a peak, together with some mechanical or pumping difficulties. Later it became imperative for the company to make an application to the State Water Policy Commission for permission to divert additional water from wells so as to meet adequately these peak demands. In the meantime, plans were prepared for a new 16-in. main to connect parts of the system in such a manner as to materially increase the volume of water available to the area that suffered in the summer of 1939.

Perhaps the most drastic shortage occurred in the Borough of Haledon. Late in the summer of 1939, the Haledon reservoir showed signs of abnormal depletion and the municipality began to seek possible means of supplementing the supply. By October, the water level had been drawn below the elevation of the normal intake pipes and the bottom intake had to be employed. Water at the lower level has never been entirely satisfactory, and added to this was the imminent probability of water shortage. Finally, it became necessary to order all of the silk industries, which probably use half of the 500,000 g.p.d. normally required, to cease taking water for industrial purposes. This action precipitated a vigorous protest, and in November a contract was made with the Passaic Valley Water Commission to take such water as could be supplied through two existing small interconnections. Immediately construction of 3,000 ft. of 12-in. main was started, and this was completed within about two weeks. Capacity of the pipe line was to be supplemented later by a booster pumping station, which could deliver sufficient water at all times for Haledon. It should be pointed out that the drastic action necessary in this instance caused entire cessation, for a period of weeks, of much of the operation of the main industry in the municipality. True, the domestic needs were satisfied, but the main-

tenance of means for making a livelihood is an obligation that should be met by any utility to the fullest extent possible.

As early as July, 1939, the city of Orange ceased drawing water from its Campbell's Pond intake reservoir, which was later reduced to a mere frog pond. Fortunately, the two wells located nearby supplied a large portion of the requirements for many months. The remainder came from an upper, or main storage, reservoir, the condition of which became acute early in January, 1940. By the second week in the month a mere two weeks' supply remained in this reservoir. The advent of a rainstorm of considerable proportions on January 14 saved the day in this case. As a mitigative measure, the city of Orange has since installed a new large capacity well, planned some new main extensions that will permit use of existing facilities to a greater degree, and taken other steps so as to prevent a repetition of the conditions of 1939 in the future.

The four large surface supplies of New Jersey, in ascending order of their storage ratio, are the Hackensack, Rockaway, Pequannock and Wanaque supplies. As mentioned before, the Hackensack supply benefited to some extent from the rains in August, 1939. This was more noticeable because of the low storage ratio. The Wanaque supply, having the greatest storage ratio, gave no evidence of recovering from the drought until March, 1940. As intermediate examples, the Rockaway supply showed a definite turn upward in January, 1940, and the Pequannock supply reached its low point in February, 1940.

Conditions on the Hackensack area were by no means as severe as those encountered in the past, and officials of the Hackensack Water Company which owns this supply had no great reason to feel alarmed. Consequently no further steps have been taken since 1939 to increase storage or other facilities, and none have appeared necessary. The reservoir filled in the middle of January, 1940.

Of the other large impounded supplies, the Rockaway supply was nearest to an actual shortage, there being but 30 days of storage left when the rains came in January, 1940. The Pequannock supply had ample reserves for some time, and the Wanaque supply was reduced to about 40% of its total storage capacity. In both of the latter supplies, the real danger that existed was the possibility of a reasonably dry period occurring during the latter part of 1940. This

was the same situation that faced the Catskill supply of New York City.

It is a matter of record now that the spring of 1940 was one of the two or three wettest known in this region. As a result, all of the reservoirs in New Jersey, as well as those of New York City, filled up readily. Had this abnormal rainfall and runoff not occurred, more than one supply would be facing precarious conditions now in the fall of 1940. Careful estimates, made early in March, 1940, showed that the Rockaway (Boonton) Reservoir would surely fill, that the Pequannock reservoirs would most likely fill, but that in only one year out of six would there be sufficient runoff to fill the Wanaque Reservoir. The probabilities of filling the Catskill reservoirs were even more remote.

That these dire predictions did not materialize was merely an act of Providence that must not be counted on too frequently by those holding positions of trust in water works. To illustrate this: a study of the records was made and it was found that the 1939-1940 dry year corresponded very closely to that of 1900-1901 until the middle of January, 1940. Had the parallel continued, more than one reservoir in New Jersey would have felt the pinch.

Under conditions that have existed during the last few months, the easiest course to pursue is to forget the past and hope that the future will not see a repetition of the conditions of 1939. This is exactly the position taken by most of the public. Fortunately, those whose lives are closely associated with these problems every day cannot forget such vivid lessons. If the drought has not accomplished anything else it has made a few more people definitely water conscious. It has also spurred the ten-year effort of the State Water Policy Commission onward to bring out forcefully the value of interconnections between the numerous sources of supply in New Jersey. This study has been going on for more than a year under the joint sponsorship of the State Water Policy Commission and the North Jersey District Water Supply Commission, with George S. Burgess, Chairman of the former, and Pearce R. Franklin, Chairman of the latter, coöperating in the undertaking. On September 16, 1940, at a meeting of the State Water Policy Commission, several interested parties were invited to express opinions as to the value of certain interconnections that have been proposed. As yet no definite ex-

pression of opinion can be given on the outcome, but at least it can be said that much progress has been made.

New Jersey is fortunate in having a water minded governor, the Honorable A. Harry Moore, who has repeatedly sought during his three terms in office to establish a sound water program on which all future progress may be planned. These views have been expressed in public, through the press, and finally in the special conference on water held with the Legislature on February 12, 1940. As a result of this meeting, a special legislative committee was formed. Reports were first made to this committee by the engineers of the various interested state bodies, and finally the governor, accompanied by the committee and engineers, presented the whole problem to the R.F.C. and W.P.A. officials in Washington for consideration of the part that the Federal government might play in financing such a project. Studies and conferences along this line have been proceeding ever since.

In closing it may be pointed out that progress is being made—even if slowly. The author is one of those who are optimistic enough to believe that some of these problems will have to be solved fairly soon. If nothing else has been accomplished, the public and the legislators have become somewhat water minded. That in itself is progress. It is to be hoped that something conclusive will be forthcoming before it is too late.

WHAT IS THE NATIONAL PLUMBING LABORATORY?

BY M. W. COWLES*

[*Read September 27, 1940.*]

We are all coming to believe that safe water in the mains is not enough—that more attention by all of us must be given to the delivery of a safe water from taps within the buildings that we supply. Everyone who has studied the problems involved in the complex relationship that exists between water distribution piping with its numerous fixtures and outlets and our public water supplies, realizes definitely that the possibilities of contamination through cross-connections or back-flow connections,[1] must be eliminated as far as possible. This Association, through its Committee on Control of Interior Piping Systems has given the question much attention.

Some progress on *prevention of direct connections* between potable and non-potable water lines or between potable water lines and sewers or drains, can be made through properly drawn plumbing codes, if they are carefully and conscientiously administered in a coöperative manner.

The *prevention of back-flow connections* is a much more difficult problem. The number and types of water-using devices supplied from potable water lines is a subject that cannot be covered in this paper. The number and types of such auxiliary devices are increasing every day and it is not easy to keep up with developments.[2] A study of actual field conditions will indicate clearly that most progress can be made if and when *each and every water outlet* into plumbing fixtures or through other water-connected devices or appliance *is designed, built, and installed* in such a way that back-siphonage under favorable conditions can be eliminated. The design of these water outlets is a problem for the manufacturer, and efforts to secure installation

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[1]A *back-flow connection* is any junction between the water distribution piping and the drainage pipes of the plumbing system. This includes the fixtures of a plumbing system and any other water-connected apparatus that will, or may, under certain conditions permit back-siphonage or back-flow from the fixture. EDITOR'S NOTE: The term *back-flow connection* is taken by some authorities to include both *cross-connections* between water supplies and *inter-connections* between water-supply and drainage systems. As used here, the term does not include cross-connections.

[2]As illustrations, ordinary faucets in lavatories, sinks, bath tubs, closet flush tanks and flush valves, dentists', doctors' and hospital equipment, air humidifiers, washing machines and many others.

of properly designed outlets are a function of the local authorities supervising plumbing. Any attempt to prevent *back-flow connections* by a plumbing code alone, without properly designed water outlets, is of little value. The subject in its entirety is much too complex to be readily written into codes, seriously interfering with the needed simplicity of interpretation and administration.

Many of the manufacturers of plumbing equipment, thinking particularly of water-connected equipment, are being hard pressed by this problem. They are anxious to coöperate, but many of them have found, after expensive changes of their patterns, especially of products sold on a nation-wide basis, that a very wide variety of state or local regulations exists, all of which are written with good intentions but with such lack of technical background that a sound, properly designed product, accepted in one community or state, may be rejected elsewhere. A desire to demonstrate in a simple manner the hazards of back-siphonage has led to the establishment of many local testing laboratories set up by health departments, water purveyors, or groups of plumbers. These have been very effective in stimulating interest in the subject. The scope of such demonstrations, however, has been enlarged to include the testing of equipment for acceptance or rejection. Test procedures have varied widely and likewise the opinions given. Those of us who have studied this problem, feel that continued increase in the number of such laboratories will serve not only to confuse the manufacturers, but also those who administer the various codes and regulations.

In 1937, the author, together with some water works operators and health officials, representing several national associations interested in the subject, formed a group for the discussion of the broader aspects of this whole problem. The opinion was expressed that the need for further study of these problems was great and that some form of testing laboratory, operating on a nation-wide basis, privately supported, unbiased in its studies and reports, should be ultimately set up so that its findings would be more and more generally accepted by all of those groups that are concerned with the safety of drinking water within buildings. This appeared at the time to be a very large undertaking and much hesitation was shown.

The National Association of Master Plumbers (N.A.M.P.) was represented in this group inasmuch as several of its members had

also been doing some progressive thinking on this whole subject leading to the establishment of some form of centralized or national laboratory for testing all plumbing equipment. This organization was anxious to coöperate actively with water works and health officials, but the whole idea continued to move slowly. Finally in the spring of 1938, the N.A.M.P., perhaps somewhat justly became impatient at the delay and actually set up a non-profit corporation that could undertake the establishment of such a laboratory. The officers of the N.A.M.P. are entitled to a great deal of credit, even though the arrangement, as originally made, was not entirely in accord with the viewpoint of some water works and health officials. A long series of conferences in which the keynote was coöperation, finally led to the formation of the National Plumbing Laboratory, on its present basis, in November 1938. In order that this laboratory might be a legal entity, a duly constituted Board of Directors was necessary. The sole functions of this board are to take care of finances and to appoint the members of the Council.

The Council has the sole power and function (entirely apart from the Board of Directors) to formulate operating policies, to develop testing methods and standards, to pass on reports of these tests, and to determine whether or not fixtures and devices are acceptable for listing. Of the twelve members of the Council, eight must be men interested and active in the field of public health, either from the viewpoint of a health department or active in some phase of the operation of public water supplies or engaged in the teaching of the problems of sanitation. Not over three members may be practicing plumbers. None of the members can be actively engaged or have any financial interest in the manufacture, sale, or installation of plumbing equipment. This arrangement of membership requirements was set up in order to secure a wide representation of viewpoint and, at the same time, eliminate any possible influence on the judgment of the members by reason of association with the manufacture or sale of equipment. All members serve without pay.

As now constituted, the Council consists of the following members:

1. M. W. Cowles, Health Officer, Hackensack Water Company, New Milford, N. J.

*2. L. V. Carpenter, Professor of Sanitary Engineering, New York University, New York, N. Y.
3. B. W. Cullen, Superintendent, Water Pipe Extension Division, Chicago, Ill.
4. A. J. Farrell, Chief Plumbing Inspector, State of Oregon, Portland, Ore.
5. W. Scott Johnson, Chief Public Health Engineer, State of Missouri, Jefferson City, Mo.
6. V. M. Ehlers, Director, Bureau of Sanitary Engineering, State Board of Health, Austin, Tex.
7. A. R. McGonegal, former Chief Plumbing Inspector, District of Columbia, Washington, D. C.
8. D. C. Williams, Commissioner, Cedar Rapids, Ia.
9. L. J. Kruse, Master Plumber, Oakland, Cal.
10. John J. Downey, Master Plumber, Boston, Mass.
11. H. L. Hopkins, Master Plumber, Charlotte, N. C.
12. F. P. Moss, Master Plumber, Miami, Fla.

Note: Appointments made prior to November 1938.

At its organization meeting in Chicago, this group adopted a procedure, after careful study, that would be followed in the testing and accepting for listing of plumbing fixtures and various protective devices, with emphasis for the present on water-connected devices attached to or used in potable water distribution piping in buildings. This material has subsequently been published in a booklet entitled "Procedure for the Council".[3] This booklet sets forth in simple and direct language, the purposes and aims of this organization, and many minor but important details governing the activities of the Council. It also places emphasis on the ways and means by which the National Plumbing Laboratory hopes to obtain its goal of safeguarding the purity of the water supply in buildings by testing plumbing equipment in a scientific and unprejudiced manner.

The services of a hydraulic laboratory that was properly equipped to do this testing work were essential, and since Dean Dawson, at the Institute of Hydraulic Research, Iowa University, had been doing work for the Research Committee of the N.A.M.P., it seemed best to have him supervise the necessary testing. The work performed in that laboratory has been excellent, and Dean Dawson, through his interest, personal attention, and personal prestige in the field of

*Deceased.
[3]Note: This pamphlet can be secured from the Secretary of the National Plumbing Laboratory, 917 Fifteenth Street, Northwest, Washington, D. C.

hydraulic research, has contributed in no small measure to the undertaking.

Within the past nine months, the members of the Council have been giving careful attention to the formulation of standardized test procedure, not only for the benefit of the Council membership in interpreting the results of the tests but also to enable manufacturers to know exactly what tests are to be made and just how they will be carried out and interpreted. This idea proved not to be a simple matter as it involves correlation of activities in many diverse fields. Terminology proved to be a knotty problem. It is expected that this test procedure, after formal adoption, will shortly be available in printed form. In the meanwhile, the text is available in the September and October 1940 issues of *Plumbing & Heating Business*.[4] This rigid test procedure thus represents the best available thought in the United States giving further assurance, if any is needed, of the quality of the work done by the National Plumbing Laboratory.

Any primary manufacturer of water-supplied or water-using plumbing equipment may submit apparatus for tests in the Laboratory. Such apparatus must be in a form ready for manufacture, not simply a rough assembly or model; it must be accompanied by complete drawings, together with copies of all advertising and publicity material, copies of which are sent to each member of the Council for review, along with the detailed report of the Laboratory giving the results of the tests made on the particular device. There is no charge for the service rendered. Each member is sent a ballot for his consideration, and 30 days are allowed for study and review. A favorable vote of three-quarters of the members of the Council will permit the device to be placed on an accepted list, and the manufacturer is so notified with the further authorization to place the seal of acceptance of the corporation on that particular product but not on other equipment made by him. If a device fails of acceptance, any limitations or shortcomings are reported to the manufacturer along with suggestions relative to improvement. No publicity whatever is given to a device that has been submitted and cannot be accepted. As far as possible, all correspondence on such matters, is so handled by the executive secretary as to stimulate continuing interest on the part of the manu-

[4]This material can be secured from Plumbing and Heating Publishing Co., 2736 Grand Central Terminal, New York, N. Y.

facturer in developing equipment or ideas that will be acceptable. Several new and very ingenious devices, distinct contributions in the art, have been developed in this way with the coöperation of the Laboratory staff.

Acceptance is divided into two grades: (1) outright or "regular acceptance" and (2), "provisional acceptance". There is a rather sharp distinction between these two grades. In general, a well designed device, containing a properly designed air-gap of sufficient size to be considered as positive protection, would receive "regular acceptance". Some other device, containing a mechanical vacuum-breaker or back-siphonage preventer, might receive "provisional acceptance", based on the fact that its ability to operate satisfactorily over a long period of years has not as yet been demonstrated. The Council may review any acceptance at any time and, further, withdraw the use of the seal of acceptance if there is any violation of the initial conditions. Any provisions relating to acceptance must be somewhat elastic to allow for improvement in the art.

To date, some 39 investigations have been made by the Laboratory and submitted to members of the Council for their vote. The results of the ballots for the last six, are not yet available. Six devices have been given regular acceptance and twelve provisional acceptance. About fifteen have been rejected, but many of them will be re-submitted in more complete form. All of the equipment tested has been voluntarily submitted by the manufacturers and, so far, no water-connected device has been purchased on the open market for testing.

Of the many problems that the National Plumbing Laboratory has faced within the past two years, the most important phase yet unsolved is that of translating the work of the Laboratory into improved installations in buildings throughout the country. The Laboratory is providing the mechanism by which properly designed devices that have passed rigid tests may be made available on the open market and the Council needs the help of all interested organizations. To put the program into effect, pressure on building owners and plumbers must of necessity, come from state or local officials having jurisdiction over plumbing and from health officials, supplemented where possible, by the active coöperation and assistance of water superintendents in their respective communities. Considerable progress has already been

made along this line through the coöperation of state plumbing inspectors where they exist and through state health departments. In these areas, many local plumbing inspectors are following the state lead. A simple paragraph in a local plumbing code will suffice.

Continued emphasis must be placed on the concentration of testing facilities in a single laboratory rather than the establishment of local testing laboratories. The confusion that will exist if we do not concentrate our efforts in this field on a single laboratory will greatly tend to retard progress in much needed uniformity and to offset possible economies that may result. Local laboratories are much more amenable to political or other pressure than is a national laboratory conducted on an unbiased basis.

All who are concerned with the installation of plumbing, with emphasis on water-supplied devices, should coöperate to prevent the further installation of new back-flow connections, including the manufacturer, the person who makes the installation, the plumbing inspector and the water purveyor. Every water works operator is in a position to be helpful to health officials and plumbing inspectors by reason of his familiarity with the elementary principles of hydraulics that are involved in the creation of pressure differences that, in turn, make possible the flow of polluted water into water distribution piping through cross-connections or back-flow connections. Increasing cooperation between these agencies, of necessity, will produce an increased appreciation of the various complex viewpoints involved. It should lead directly to the installation of water distribution piping, including fixtures and other water-connected devices that will, by virtue of proper construction, reduce back-siphonage or contamination hazard to the lowest possible degree. It should be possible to erect new buildings that are reasonably free from the hazards of back-siphonage.

The National Plumbing Laboratory is making a definite contribution toward protection of water lines in new buildings, through its rigid test procedure and the issuance of the seal of acceptance. It is operated on sound principles. The further development of methods of application in the field should be of great importance to manufacturers of this class of equipment as well as to health department officials, building owners, plumbers and water purveyors. The ultimate objective of the N.P.L. can be obtained in each community through

a process of education leading toward the simple requirement that all water-connected devices or water outlets installed shall be of a type chosen from the "accepted" list. The help and coöperation of every water works superintendent will encourage us to push on toward the much desired goal.

HI-CO, A NEW TAR COATING TO MAINTAIN HIGH COEFFICIENT OF FLOW

BY H. J. BILLINGS*

[*Read September 24, 1940.*]

This paper describes a new tar coating for cast-iron pipe which is now available under the trade name of HI-CO, a coating which affords adequate protection against corrosion without being subject to the defects commonly associated even with the more expensive coatings heretofore available.

The deterioration in cast-iron pipes is usually in carrying capacity, rather than in loss of strength of the material, and if it comes at all, deterioration usually shows itself as small buttons of rust, known as tubercles formed by corrosion of the pipe when in contact with unusually soft water. Successive layers of these tubercles may be formed with the passage of years, thus reducing the effective diameter of the pipe and its carrying capacity. Actual pitting of the cast iron beneath the tubercles is practically negligible. Tuberculation is not a universal phenomenon; its most serious form is, however, found in New England and in some sections of the Southeast. Tuberculation in pipes lined by the ordinary tar-dip process is due to pin-holes or defects in the lining, and attempts to eliminate it have resulted in the development of bituminous and cement linings, both applied centrifugally to the interior of the pipe. Despite their success in avoiding contact between water and the cast iron, these coatings have two major objections: they significantly increase the cost of the completed pipe and their thickness reduces its carrying capacity. In an endeavor to overcome these objections the problem was taken to the research laboratories of Arthur D. Little, Inc., of Cambridge, Massachusetts.

An exhaustive survey of many potential means for protecting cast-iron pipe disclosed few that were sufficiently economical to warrant consideration. Among these, there were so many points in favor of coal tar that it was decided to direct every effort toward its more

*Research Department, Arthur D. Little, Inc., Cambridge, Mass.

effective use. Particularly important was the fact that it had long been accepted as a satisfactory material for use in contact with drinking water. It was apparent that the work should be directed towards a means for holding in place a lining of adequate thickness and evenness to preclude the presence of pinholes in which corrosion might be initiated, but not be so thick as to reduce the effective diameter of the pipe. This coating must be so firmly bonded to the pipe that it would not flow or peel off when subjected to hot weather, and tough enough not to chip or flake off when roughly handled during cold weather.

After considerable investigation it was found possible to meet all these requirements by applying to the interior of the pipe a composition of coal tar and mineral fillers, coking this at relatively high temperature to obtain a porous lining of carbon and mineral filler tenaciously attached to the pipe, and then saturating this porous coat with tar during an automatically controlled tar-dipping step. The function of the under-coat is to provide a tough, hard, infusible, insoluble, and firmly bonded framework that will absorb and hold the tar which is later applied. During the high temperature just preliminary to coking, the under-coat composition flows easily enough to smooth out any irregularities in the pipe as cast and, after coking, presents a smooth, satin-like surface.

The under-coat composition in commercial use consists of a light water-gas tar containing a definite percentage of finely-ground slate flour. The addition of the slate filler gives it body and thickness, and compensates for that portion of the tar which is driven off during coking. The tar ordinarily used in dipping is applied as the second, or saturating coat. The complete thickness of the under-coat is 1½ to 3 thousandths of an inch, while the thickness of the final two coats is 4 to 5 thousandths of an inch.

The coke-tar lining, which is now commercially available under the trade mark "HI-CO", is well suited to production in the cast-iron pipe foundries that are now equipped for tar dipping. The under-coat composition is applied by a spray nozzle which is drawn through the pipe and ejects the composition from its entire circumference. The pipe is then rotated over each of a series of gas burners, which raise its temperature to 550° F. for a period of a few minutes, during which time a yellowish green cloud of smoke is given off and dis-

appears as coking is completed. Following coking, the pipe is cooled to the proper temperature and dipped in the customary manner in the tar bath for the second coating. After a brief cooling the pipe is hydrostatically tested to 500 lb. per sq. in. pressure and sent to storage.

During and after the development of the "HI-CO" lining, considerable attention was given to determination of the permanence and effectiveness of the protection that the lining afforded, and, while the testing of a long-lived material such as cast iron by accelerated methods is naturally difficult, definite indication of the perfection of the lining may be obtained by several methods.

The continuity of the "HI-CO" lining is easily demonstrated by an attempt to pass an electric current through it. In conducting this test, pipes coated with "HI-CO" and with ordinary tar were sealed to a wooden base with molten coal tar and filled with a 3% solution of ammonium chloride. A brass rod suspended in the center of the pipe was used as the anode and the pipe metal as the cathode. The amount of current passed by this circuit is directly related to the area of metal exposed to the solution. When a potential of 9 volts was applied to the circuit, ordinary tar-dipped pipes passed a current of 1 to 4 amperes, while "HI-CO" pipes passed no current whatever.

A more visual test is obtained by filling the pipes with a strongly acid copper sulfate solution. If this solution is allowed access to the iron through any pin-holes present in the lining, a readily apparent deposit of copper is formed. The test is quite sensitive; ordinary tar-coated pipes tested by this method are peppered with deposits after a few hours while in the great majority of instances "HI-CO" pipes showed no copper deposit after 12 hours. In the testing of many pipes an occasional pin-hole was discovered, but the indications are that because of the cellular nature of the under coat and its firm bond to the pipe, such corrosion will not spread beyond the point of initiation. A second corrosion test was conducted by immersing coated pipes in a 3% ammonium chloride solution for several days. It was found by this test that ordinary tar-dipped pipe would show very considerable rusting at the end of one week, whereas a "HI-CO" pipe showed no sign of rusting at the end of two weeks.

In order to test the resistance of the lining to shock, sections of pipe were subjected to low temperature and then struck with a

hammer. It was found that bituminous lining was extremely brittle and cracked away from the pipe at a temperature of 10° F., while the lining of the "HI-CO" pipes could not be cracked after being subjected for 24 hours to a temperature of minus 30° F. One notable defect of bituminous lined pipes has been the tendency of the linings to flow and separate from the pipe when exposed to the sun on hot days. Because of the infusible nature of the "HI-CO" undercoat and its firm bond to the pipe metal, the protective tar topcoat is held in position despite subjection to temperatures considerably above those met in practice. In testing this characteristic, "HI-CO" pipes were placed in an oven with close temperature control and allowed to remain for 24 hours at a temperature as high as 140° F., with no appreciable softening of the lining and no tendency to sag.

Actually yard storage of pipe, where it is exposed simultaneously to air, moisture, and sunlight, is itself one of the best accelerated tests for a lining, ordinary tar-dipped pipe showing definite signs of corrosion after a matter of a few weeks. "HI-CO" pipes have now been exposed for two years to year-round weather and are still in excellent condition. Also during the period of nearly two years since the first "HI-CO" linings were produced, it has been possible to conduct an actual service test. This was supervised by J. E. Gibson, Manager of the Water Department of Charleston, South Carolina, where the water is extremely soft and corrosive. The line tested was 300 ft. in length, consisted of 6-in. Sand Spun Bell and Spigot Pipe with "HI-CO" lining, and was laid in January 1939. The Williams-Hazen coefficient was determined on three subsequent occasions and showed that there has been no measurable decrease in capacity during the period from January 1939 up to June 1940. It appears therefore that a coal-tar-lined pipe that will give many years of trouble-free service is now available.

MILFORD WATER COMPANY CONSIDERS CATHODIC PROTECTION

BY M. H. GOFF*

[*Read September 27, 1940.*]

In the water works field, the subject of cathodic protection is being widely discussed, and many New England cities and towns have contemplated such installations. Informal discussions have taken place between New England superintendents, and all are agreed that this method might be the end of the maintenance worries connected with standpipes and elevated tanks. It is generally acknowledged that electric devices for the prevention of corrosion appear to be promising but that their acceptance in a large way will probably be withheld until evidence of actual operating results can be obtained.

Water works engineers throughout the West have written many instructive papers on this subject, and the data presented have been given much consideration by those interested in the matter. Cathodic protection of water tanks has been applied in the Middle West for many years, and installations are reported to have given satisfactory results. This can be realized from papers written by Earl E. Norman, General Superintendent, City Water Department, Kalamazoo, Michigan, and W. C. Mabee, Chief Engineer, Indianapolis Water Company, Indianapolis, Indiana. Much interesting information can be obtained from their articles.[1]

The apparatus needed for the cathodic protection of standpipes and elevated tanks consists of long rods, called electrodes, that are suspended from the top of the tank into the water to a specified depth. The number of electrodes, their size and length is determined by the capacity of the tank. On the side of the tank, or other suitable location, is installed a rectifier, which converts alternating current to direct current. This feeds the electrodes suspended from the roof of the tank. All feed lines are insulated throughout.

The other important features of cathodic protection are the

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*Superintendent, Milford Water Co., Milford, Mass.

[1]Journal of the American Water Works Association, **32**, July, 1940.

electrodes and the different types of material that may be used for them. Stainless steel, carbon or graphite electrodes may be employed. Continuous research is being conducted along these lines, with the manufacturers ready to adopt any superior material that may become available for their purpose. The important features pertaining to electrodes are their efficiency, durability, and current consumption. During the past three years there have been only a few cases where noticeable deterioration of electrodes has taken place. These have occurred where the water contained excessive quantities of sulphur. Replacement of electrodes in such instances will be more frequent than where such water conditions do not exist. In any event, it is much easier and less expensive to replace electrodes occasionally than to repair or repaint an old tank. A special type of stainless steel will be used in our installation.

It is interesting to note how this system of rectifier and electrodes prepares the tank for rust-proofing. A positive wire extends from the rectifier unit to the electrodes and a negative wire from the rectifier to the pipe line entering the standpipe or elevated tank. The entire tank becomes negative under these conditions. The water in the tank becomes a medium that conveys a charge of electricity from the electrodes to the walls of the tank. The rectifier unit is provided with a volt meter and ammeter and regulates the amount of current required for each installation. On old tanks that are already corroded, the cathodic system will definitely remove scale and other products of corrosion and deposit a protective film on the clean steel to prevent any further corrosion. The cathodic system will cleanse the inside walls of a tank much more easily than is possible by scraping or wire-brushing. If the interior of the tank has been painted, cathodic protection will prolong the life of the tank so long as the paint is sound and intact. Should the paint begin to deteriorate and water seep under it, this system protects the metal and gradually removes old scale or rust that may have accumulated. Eventually old scale and paint will disappear and the protective film underneath will be sufficient to prevent any further rusting of the metal.

It is recommended that the tank be kept as full of water as possible at all times for best results, during the first three months after installation. This enables the film to become established on the walls of the tank. Later on, the water level may be lowered in the

tank, or the tank may remain empty for several weeks before the protective film is broken. All reports give definite proof of rust and corrosion removal from rivet heads and other important points in the interior of elevated tanks or standpipes. The cathodic system is now successfully installed on tanks ranging from 1,000 to 5,000,000 gal. Therefore, it is quite evident that cathodic protection has been proved to be more efficient and economical than any other known method.

One serious obstacle confronting New England water works operators, is the formation of ice at the top of standpipes or elevated tanks. We can all visualize the action of three feet of ice on small stainless steel rods suspended from the top of a tank. A method has been devised of heating the area around each individual electrode, thus melting the ice around the rod. This seems to work quite well if the ice at the top of the standpipe remains in one solid cake. In order to determine what ice conditions existed in the 1,200,000-gal. uncovered standpipe at Milford, the tank was filled to overflowing during severe winter weather and the ice allowed to fall over the top. As expected, the ice did not form one single cake, but occurred in broken pieces of tremendous weight and size. One can easily understand why rods are not in good condition in the spring. Trouble, of course, may be avoided by removing the cathodes each fall, and resetting them in the spring. However, this is more easily said than done. The alternate suggestion would be a cathodic system installed in the standpipe by means of an underwater structure of electrodes, so that ice would not reach any of the electrodes. Such an installation would be free from all ice hazards.

More electrodes are used in this arrangement, because of the shorter length of rod. The structure for a 1,200,000-gal. cylindrical tank, not covered, has a standard or platform 15 ft. high, in the shape of a 17-ft. triangle, made of 1½-in. steel angles, reinforced with light steel flats, or angles. This structure serves as a base for the 30-ft. electrodes. These consist of six ¾-in. round, stainless, alloy-steel bars, 30 ft. in height, and braced at intervals to protect against unusual surges of water in the tank. The standpipe at Milford is 85 ft. in height, and the water level never drops more than 20 ft. in the tank. Therefore, ice would never reach the structure of electrodes under this design.

This type of installation costs about $1,400 complete, or approximately $500 more than for the suspended installation. This compares favorably with costs of sand blasting, wire brushing, and painting the interior of the tank.

In covered elevated tanks, electrode suspension from the roof has been successful. The elevated tank, being enclosed, is warmed to some degree by the sun's rays in the winter months. This may be sufficient, in some circumstances, to reduce the ice hazard, although special heating units may have to be supplied to keep the electrodes free from ice.

The power costs of cathodic protection are small and probably will not exceed $20 per year. This estimate is based on a high commercial electricity rate.

In conclusion, the benefits of electric cathodic treatment for the interior of standpipes and elevated tanks may briefly be summed up as follows:

1. Splendid action in arresting all corrosion.
2. Excellent protection which is well warranted for such costly investments as an elevated tank or standpipe.
3. Extremely low maintenance costs.

Summary of Discussion

It was brought out in the discussion that installation of electrodes from the bottom had never been attempted before. Sidney S. Anthony, Augusta, Me., reported that it was the practice to withdraw the electrodes of the Augusta tank during the winter. Warren J. Scoot (Hartford, Conn.) called attention to the necessity of safeguarding the water in the tank against pollution during the installation of cathodic equipment. Chlorination of the tank and the electrodes was suggested. Robert Spurr Weston, Boston, Mass., told of installing electrodes successfully in steel pressure filters at Sanford, Me. Rust removal, it was stated, must be expected to result in increased leakage.

SANITATION AND PURIFICATION OF NEW YORK CITY'S WATER SUPPLIES

BY FRANK E. HALE*

[*Read September 27, 1940.*]

It is the author's intention to present a survey of the various methods by which New York City's water supply is safeguarded. The work of the Watershed Divisions and of the Laboratory Division supplement each other. The former operates the sewage disposal and chlorination plants on the watershed, the latter controls the operation by the various analyses made and by the interpretation of those analyses.

The consumption of water by New York City, 980 m.g.d., or approximately one billion gallons daily, is most strikingly presented by picturing this amount of water stored in 50 gallon hogsheads standing on end side by side. It would take 20 millions of these, and they would stretch from Gibraltar across the Atlantic Ocean, across the United States and out into the Pacific Ocean, a total distance of about 8000 miles or one-third the circumference of the earth. And yet every drop of this water must be fit to drink. If it were necessary to distribute such an amount of water in water-tight bags slung over mule back, as is still done in some backward countries, one can well imagine the difficulty of delivering such a quantity of water daily in sanitary condition.

The water supply of New York City is one of the largest and most complex of any city in the world. In addition to the extensive surface supplies—the Catskill, the Croton, the Bronx, and Long Island supplies—there are also numerous well sources furnishing amounts of water equal to the supplies of many small cities. The watershed areas in round numbers cover over 1100 sq. miles, in detail as follows:

	Sq. miles
Catskill	571
Croton	375
Bronx	22
Long Island	168
Total	1136

*Director of Laboratories, Bureau of Water Supply, City of New York.

This tabulation does not include the well systems within the city limits, some of which are owned by the city and some by private water companies. Staten Island is supplied partly by Catskill water but also by well systems owned by the city at Grant City and Tottenville. The city has well systems in Queens and in Brooklyn. The Flatbush area of Brooklyn is supplied by the New York Water Service Corporation. Woodhaven is supplied by this same company. Jamaica is supplied by the Jamaica Water Supply Company. The quality of these well supplies is also under control of the Commissioner of Water Supply.

Storage. The first line of defense of the surface waters is the very extensive storage. Catskill water is temporarily retained in Schoharie Reservoir, capacity 20 billion gal., and gets long storage in Ashokan Reservoir, 130 billion gal. With an average draft of 600 m.g.d., there is a theoretical storage of over six months. However, there are two Ashokan basins, the west basin holding about one-third the capacity, and the east basin two-thirds. Draft is at the dividing weir. Following heavy storms, floating débris reaches Ashokan Dam within one or two days, hence at such times theoretical storage disappears. The water drawn usually passes through a portion of Kensico Reservoir requiring about three weeks, hence this amount of storage is practically always available. The importance of this consideration is seen in the fact that any typhoid germs reaching the water supply will die out to the extent of about 99% in two to three weeks' time. In two months' time, practically no typhoid germs would survive.

Water may be water, but its quality is not the same at all depths in a reservoir. Samples are taken from both the west and east basins of Ashokan Reservoir, at the top, middle, and bottom so that the point of draft may furnish the best quality of water. This is of importance particularly in connection with the turbidity of the water. Very turbid water frequently develops at the bottom of the west basin first. The top water is allowed to flow over the dividing weir and mix with the clearer water of the east basin from which water is then drawn. The effect of storage in reducing bacteria is shown in the following table of analyses made during the first four years that Ashokan Reservoir was put into service (Table 1).

It will be noted that during the fourth year *B. coli* was removed to the extent of 99.8%.

TABLE 1—EFFECT OF STORAGE AT ASHOKAN RESERVOIR

	Esopus Creek above Boiceville					Ashokan Reservoir Screen Chamber				Percentage Removal	
		B. coli-per cent					*B. coli*-per cent				
	Bacteria	0.01 c.c.	0.1 c.c.	1.0 c.c.	10.0 c.c.	Bacteria	0.1 c.c.	1.0 c.c.	10.0 c.c	Bacteria	*B. coli*
1915	116	0	13	53	93	178	10	10	50	0	40
1916	171	0	0	36	73	55	0	18	55	68	46
1917	97	0	7	48	77	24	0	0	32	75	97
1918	123	8	10	35	73	38	0	0.3	12	69	99.8

Kensico Reservoir holds 30 billion gal. Into this reservoir also flows the water gathered on the Bronx watershed. This storage would furnish at least a month's supply in case it became necessary to shut off the aqueduct between Ashokan and Kensico reservoirs. The Croton water is stored in large reservoirs and lakes, about 18 in number, so arranged that water passes from one reservoir to another. It finally enters Croton Lake 20 miles long and holding 34 billion gal. The total storage of the Croton reservoirs is about 104 billion gal. This again represents about two-thirds of a year's storage at maximum draft. Long Island water has very little storage, the largest reservoir being Hempstead Storage Reservoir, which holds one billion gal. This reservoir and the Long Island ponds are all spring-fed.

In addition to the time element, the storage reservoirs are great equalizers, rendering water of more uniform quality. In large reservoirs, there is another factor: the question of stagnation or vertical circulation. During the winter the water circulates from top to bottom and is of uniform quality. Beginning in May, circulation is confined to the upper 30 ft. of depth. There is formed what we term a "thermocline" (Figs. 1, 2, and 3). The thermocline forms at that particular depth in a reservoir below which the water remains practically stagnant. At this point there is a sharp drop of temperature within a few feet, but above this point the water is circulated by wind and wave throughout the summer. For several years, samples were taken by the Laboratory Division at small intervals of depth from top to bottom in both Kensico Reservoir and Croton Lake. Determinations were made of temperature, dissolved oxygen, carbonic acid gas and microscopic organisms. These analyses show that what we term "liquid

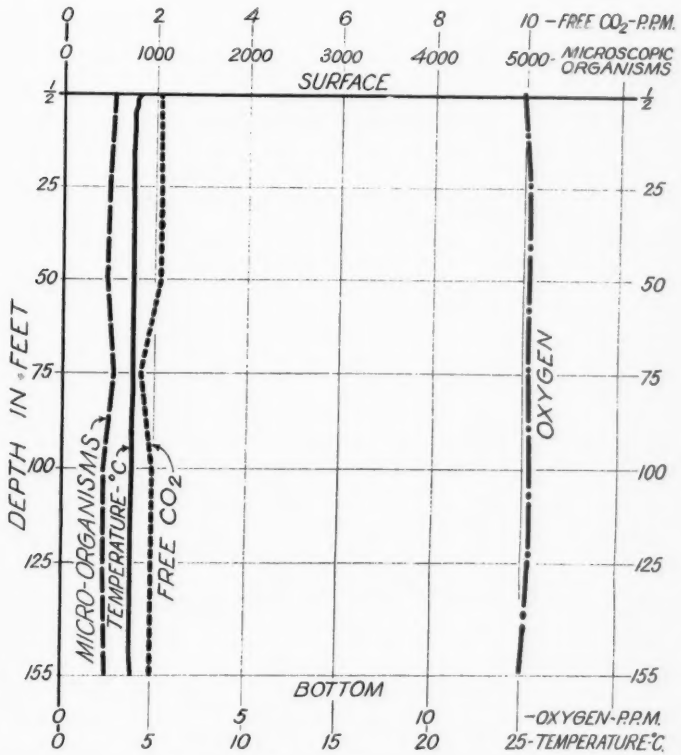

FIG. 1.—QUALITY OF WATER IN KENSICO RESERVOIR AT VARIOUS DEPTHS IN THE ABSENCE OF A THERMOCLINE. APRIL 4, 1917.

combustion" takes place in the deeper water of the reservoirs. Organic matter and dying microscopic organisms settle to the thermocline, and the organic matter is burned up by the dissolved oxygen in the water, forming carbonic acid gas. We are familiar with this process in the heating furnaces of our homes. We shovel in coal and turn on the draft, and the organic matter of the coal (carbon) is burned by the oxygen of the air to form carbonic acid gas that goes up our chimney. Just so in the reservoir, dissolved oxygen frequently becomes reduced to zero just below the thermocline and at the bottom of the reservoir

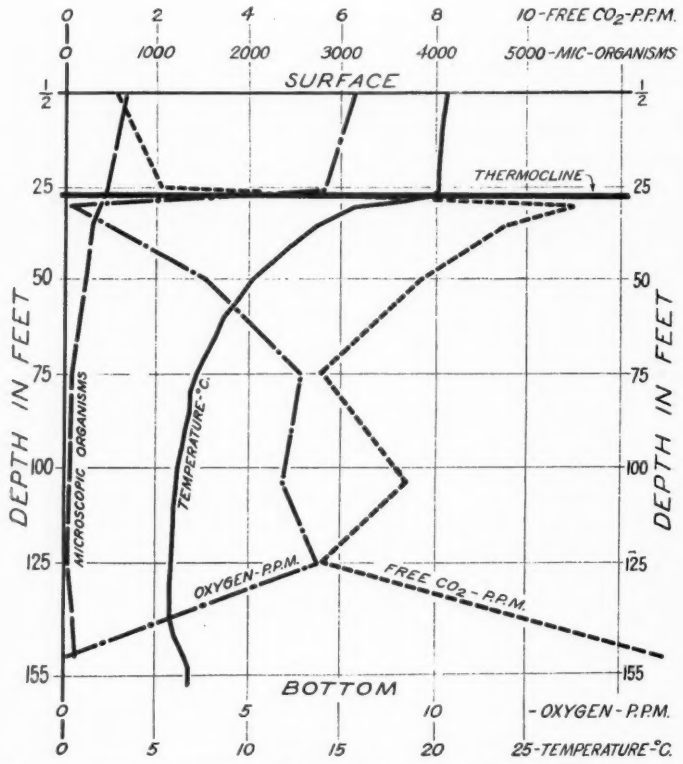

FIG. 2.—QUALITY OF WATER IN KENSICO RESERVOIR AT VARIOUS DEPTHS WITH THERMOCLINE AT A DEPTH OF 27 FEET. SEPTEMBER 22, 1916.

to which organic matter settles. In between are various reduced quantities of dissolved oxygen. Proportionate to the reduction of oxygen, there is an increase in carbonic acid gas. Figures 2 and 3 illustrate how these quantities vary in opposite directions throughout the summer season. The practical application of these studies is made by drawing water from about 60 ft. or below at both Kensico Reservoir and Croton Lake. This procedure was started in 1912 at Croton Lake and resulted in furnishing water to the city five to ten degrees cooler than the surface water and with about 75% fewer microscopic

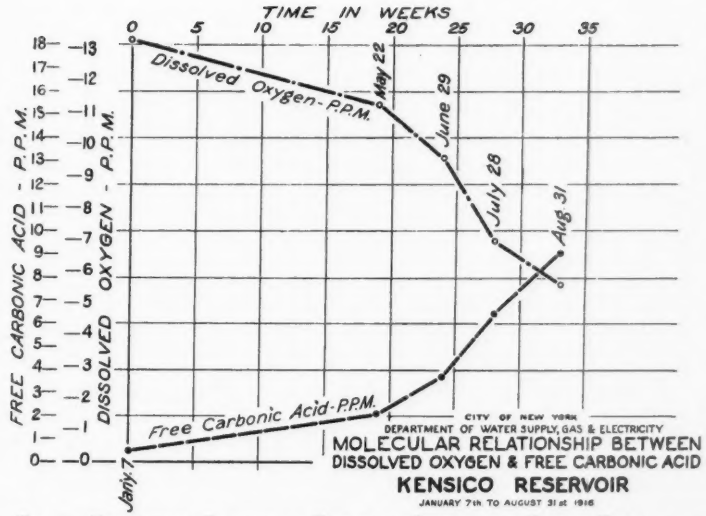

FIG. 3.—PROGRESSIVE CHANGES IN DISSOLVED OXYGEN AND CARBON DIOXIDE IN KENSICO RESERVOIR. JANUARY 7 TO AUGUST 31, 1916.

organisms, thus avoiding much taste and odor. This is shown further in Table 2.

TABLE 2—REDUCTION OF MICROSCOPIC ORGANISMS BY DEEP DRAFT. CROTON SUPPLY—JULY, AUGUST AND SEPTEMBER

Year	Temperature °F.	Micro-Organisms St. Units per c.c.	Reduction Per Cent
1911	72	2,836	—
1912	67	1,072	65
1913	65	677	75

Deep-water samples are taken by the two-bottle method. A one-quart bottle is attached to the side of a two-quart bottle with glass tubing so arranged through rubber stoppers that the water must enter the smaller bottle first and pass into the larger bottle. The tubing is of such size that it takes four minutes to fill both bottles while it takes only two minutes to lower the equipment to the bottom of the deepest reservoir. Consequently, the small bottle is filled with the

last water to enter, and represents the water at the depth to which the equipment is lowered.

Aeration. Catskill water as it leaves Ashokan Reservoir and again as it leaves Kensico Reservoir passes through huge aerators 500 ft. by 250 ft. in plan and containing 1600 nozzles each. This freshens the water, adding oxygen, decreasing carbonic acid gas and reducing odors of decomposition and odors due to microscopic organisms. Certain fragile organisms are knocked to pieces.

Sewage Disposal. Naturally, upon extensive watersheds, there are numerous villages. It is impracticable to remove all dwellers from these areas. The Department has established sewage disposal plants at several points on the Croton watershed, and the Board of Water Supply and the Department have done likewise on the Catskill watershed. These plants represent various types of disposal and produce effluents similar to well water. No plants in the world produce better results. On the Catskill area, there are plants at Tannersville, Grand Gorge, Pine Hill and Chichester; others are under consideration at Hunter and Windham. On the Croton watershed, there are plants at Brewster, Mt. Kisco, Lincolndale, Montefiore Home, Bedford, Westfield State Farms, and (recently constructed) Carmel. In the Bronx there is a plant for Jennie Clarkson Home. On the Long Island watershed there is a plant at the Navy shell factory, Baldwin. The separate villages of Rockville Center and Freeport have their own plants. The pan system and care of cesspools is still maintained at some points on this watershed.

In general, the treatment of sewage is covered by three processes: (1) some form of digestion of the sludge, where again wet combustion may be said to take place; (2) sand filtration to separate the water from the sludge; and (3) chlorination to destroy practically all bacteria. Analyses are made at every stage of the process, thus indicating what methods are most effective and certifying the final results. Studies of the results at the Mt. Kisco Sewage Disposal Plant, made several years ago before it was remodeled, are shown in Figure 4. Attention is called to the continual decrease in oxygen demand, that is oxygen consumed by wet combustion throughout the various stages of treatment and ending at zero. The amount of purification accomplished in the septic tank and the increase of solids and of nitrate in the sand filters, caused by fixation of carbon dioxide and oxygen,

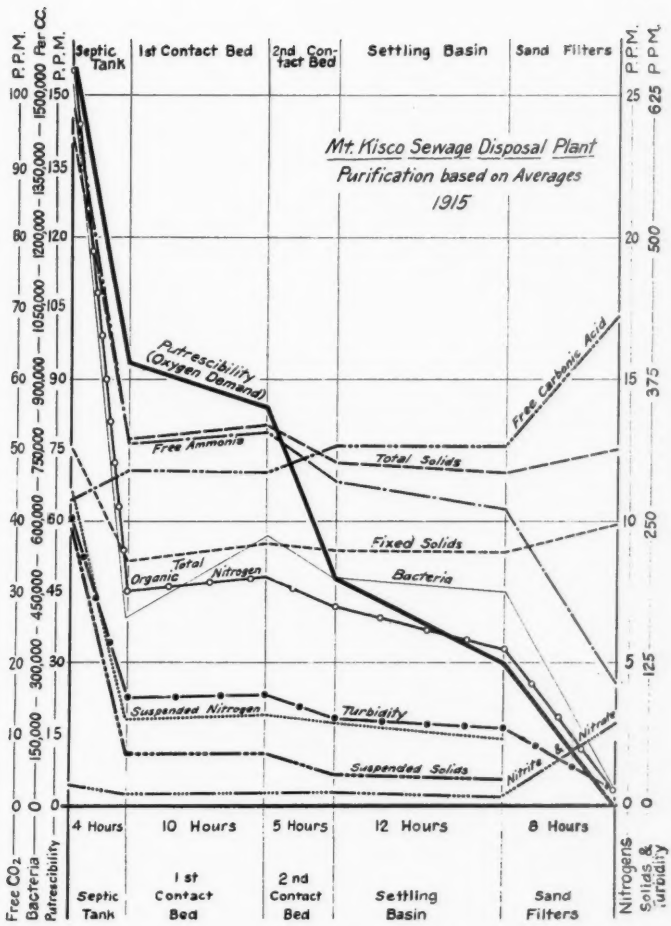

FIG. 4.—AVERAGE PURIFICATION OF SEWAGE AT MT. KISCO. 1915.

should also be noted. Table 3 shows average results for 1939 of complete analyses of raw and chlorinated filtered sewage of the remodeled plant, Imhoff tank, half through trickling filter, sand filters, and chlorination. The character of the final effluent is seen to be like that

TABLE 3—PERFORMANCE OF MT. KISCO SEWAGE DISPOSAL PLANT

Chemical results are expressed in p.p.m.

	Pumping Station	Chlorinated Effluent	Percentage Removal
Turbidity	202	8	96
Organic nitrogen (Kjeldahl)	12.4	1.84	85
Ammonia nitrogen	17.4	3.26	81
Nitrite nitrogen	0.065	0.005	92
Nitrate nitrogen	0.14	14.37	+
Total solids	475	355	25
Loss on ignition	290	189	35
Fixed solids	185	166	10
Chlorides	29	44	+
Bio-chemical oxygen demand	134	0	100
Bacteria per c.c. 37° C.	352,615	60	99.98
B. coli per 10 c.c.	593,270	0.4	99.99993

of well water and requires that percentage removal of bacteria be expressed to five or six decimals.

The Tannersville Sewage Disposal Plant represents one of the plants on the Catskill Watershed. The sewage passes through a Doten

TABLE 4—PERFORMANCE OF TANNERSVILLE SEWAGE DISPOSAL PLANT

Chemical results are expressed in p.p.m.

	Raw Sewage	Doten Tank Effluent	Filter Effluent	Chlorinated Effluent	Percentage Removal
Turbidity	46	22	4	4	91
Color	—	—	9	7	—
Organic nitrogen (Kjeldahl)	10.1	3.2	1.1	0.97	90
Ammonia nitrogen	6.8	2.3	0.2	.16	77
Nitrite nitrogen	0.015	0.013	0.008	.000	100
Nitrate nitrogen	0.28	0.29	5.60	5.79	+
Total solids	127	78	104	108	15
Loss on ignition	68	36	44	41	40
Fixed solids	59	42	60	67	+
Chlorides	7.7	4.5	8.3	12.0	+
Bio-chemical oxygen demand	26	13	0.2	0	100
Bacteria per c.c. 37° C.	264,580	127,720	28,500	17	99.994
B. coli per 10 c.c.	675,400	185,200	2,240	0.03	99.999996

tank and sand filters prior to chlorination. Results for 1939 are shown in Table 4.

The chlorine dose was 3.7 p.p.m. as shown by the increase in chlorides. Trout swim without discomfort into the effluent as it enters the creek. Such an effluent is practically equal to good drinking water. *B. coli* tests are made on 100 c.c. quantities.

Chlorination. All surface water is chlorinated at least twice, and all wells that require it are chlorinated. In 1937, there were 122 points equipped for chlorination, and 59 plants were operating. Fifty of these plants are owned by the city and 36 were operated by it. The chlorination of wells by the private water companies is generally instituted for the purpose of controlling *Crenothrix,* other iron bacteria, and certain fungal growths that cause taste and odor or sediment in the water. Plants range in capacity from those for single wells to those treating 650 m.g.d. or more. The Catskill water is chlorinated as it flows from Ashokan Reservoir, again as it is discharged from Kensico Reservoir, and once more as it leaves Hillview Reservoir. Chlorination will also be provided for the new Delaware supply, the final point being at Hillview Reservoir. This plant is in fact now operating on Catskill water. Croton water is chlorinated as it is pumped to the Catskill Aqueduct at Croton Lake. The new aqueduct is chlorinated at Croton Lake and at Dunwoodie, the old aqueduct at Dunwoodie and at 135th St. Gatehouse. The Long Island supply is chlorinated at Massapequa Pumping Station, Milburn Pumping Station, Clear Stream Pumping Station, Hook Creek Pumping Station, Watts Pumping Station when operating, and finally at Ridgewood Pumping Station. Numerous plants exist upon the Croton watershed above Croton Lake. Chlorination is being planned for the treatment of the distribution reservoirs in the city, Jerome Park, Central Park, Ridgewood, and Silver Lake. Chlorination is so maintained that residuals at the plant are between 0.05 and 0.10 p.p.m. This eliminates complaints of taste, and yet the water supply to the city is usually free from *B. coli* in 100-c.c. quantities that are tested daily.

At the larger plants, such as Ashokan, Kensico, Hillview and Dunwoodie, ton containers of chlorine are employed. Control equipment is furnished by the Laboratory Division to the numerous plants, by which the operators may so regulate the dose of chlorine that the range of residual free chlorine is maintained between the limits de-

sired. This is done by adding an indicator, the orthotolidin dye, that produces a color after a definite interval of time and may be compared with color standards. By this simple method, the control prevents complaints of taste and odor and yet assures the removal of all injurious bacteria. Twice a year, the Laboratory Division visits the important plants and by test at the plant determines the effective dose required as a check upon the plant results. Such a test is shown in Table 5. A chlorine solution was used of such strength that 1 c.c. added to 100 c.c. of distilled water gave 0.33 p.p.m. of chlorine. Absorption time was 10 minutes before adding the orthotolidin.

TABLE 5—TEST OF CHLORINATION

	Check of standards—p.p.m. of chlorine.												
Mt. Prospect*	.00	.02	.04	.06	.08	.10	.15	.20	.25	.30	.35	.40	.50
Kensico	.00	.02	.04—	.06—	.07	.09	.13	.20	.23	.28	.33	.38	.50

Residual chlorine (p.p.m.) after stated time (min.)	Experimental Dosage—p.p.m.			Test of plant results	
	.16+	.24+	.33	Raw Water p.p.m.	Chlorinated Water† p.p.m.
5	.03	.04	.10	.01	.04
15	.05	.07	.12	.01	.06
30	.06	.08	.13	.01	.07

*Mt. Prospect is the control laboratory.
†Dosage equalled 0.24 p.p.m.

These experimental results are frequently astonishingly close to the plant results. Note the agreement between experimental results, with a dose of 0.24 p.p.m., and plant results.

Figure 5 indicates how the amount of chlorine absorbed by various waters, such as the Catskill and Croton waters, differs greatly throughout the year, thus indicating the importance of this control. The larger absorption by surface waters than by well waters should also be noted. Absorption value is influenced largely by growth of microscopic organisms.

Typical results for bacteria removal at the Kensico plant are shown in Table 6 (years 1938 and 1939).

Typhoid Fever. All typhoid cases on the watersheds are ascertained by the Watershed Division. At the present time this is a very rare occurrence. Cases reported within the city limits by the Board

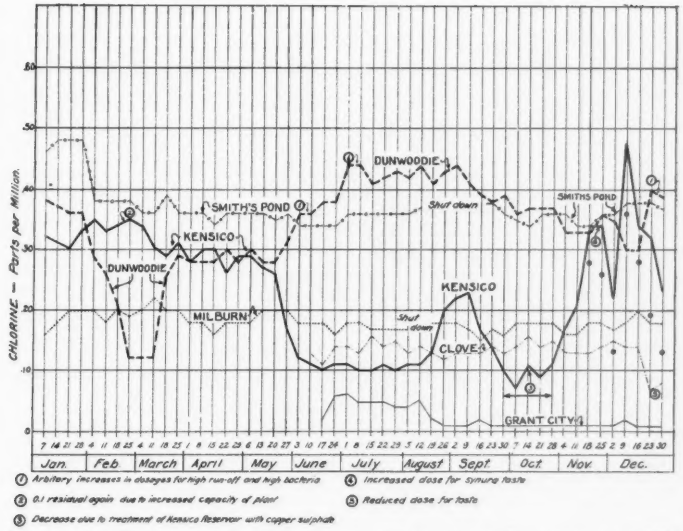

FIG. 5.—ABSORPTION OF CHLORINE AT THE CHLORINATION PLANTS DURING 1922. TESTS ARE BASED ON A RESIDUAL OF 0.10 P.P.M. OF CHLORINE AFTER A CONTACT PERIOD OF 10 TO 30 MINUTES AND ON COLOR DEVELOPMENT IN ORTHOTOLIDIN IN 10 MINUTES.

TABLE 6—BACTERIAL REMOVAL BY KENSICO CHLORINATION PLANT

Available chlorine applied— p.p.m.	Raw Water		Chlorinated Water		Percentage Removal	
	1938	1939	1938	1939	1938	1939
Theoretical	—	—	.30	.27	—	—
Analytical*	—	—	.26	.24	—	—
Bacteria per c.c., 37°C.	19	16	2	2	89	87
B. coli index per 100 c.c.	6	10	0	.003	100	99.97

*Represents the chlorine applied at the time of sampling as determined by increase in fixed chlorides. The theoretical dosage is obtained by loss of weight of chlorine in the cylinders and flow measurement by Venturi meter.

of Health are carefully studied by the Laboratory Division and charted each year. Samples of water are collected by the Board of Health from all buildings where typhoid or diarrheal cases occur and brought to our laboratory for examination. In past years, the location of these cases in connection with draft of water has been studied, and these

studies have indicated that the water supply has had no connection with typhoid fever cases since the introduction of chlorination.

In 1907 there was a rise of typhoid in the spring equal to that occurring in the fall. In that spring, an epidemic of typhoid occurred in Katonah, on the Croton watershed. Undoubtedly, it was the cause of the rise of cases in the city, though Katonah is situated ten miles above the point of draft from Croton Lake. In this same year, an epidemic occurred in Richmond due to surreptitious addition of surface water to well water by a private water company. The source was cut out of use, and 17 days later the epidemic stopped abruptly. An epidemic occurred in Brooklyn many years ago which was investigated by the Laboratory Division in detail. The cases were grouped about an ice cream parlor. Analyses of the ice cream showed it to be highly contaminated. These facts were called to the attention of the Board of Health, and a typhoid carrier was found to be employed at this ice cream parlor. In 1916, Brooklyn was supplied from Long Island sources entirely. In 1917, Long Island water was discontinued and replaced by Catskill water. The typhoid rate for Brooklyn in the two years was exactly the same, four deaths per 100,000 population. This surely indicated no relation of water supply to typhoid fever, At the time that the Laboratory Division was started, the typhoid death rate of New York City was approximately 20 per 100,000. For the last three years this rate has been only 0.3. This shows the practical elimination of typhoid fever from the city.

Turbidity. Heavy storms cause turbidity in the Catskill water practically every year. The particles are in such fine colloidal condition that it has taken six months to reduce their concentration from 100 p.p.m. to 10 p.p.m. in Ashokan Reservoir. Treatment of the Catskill supply takes place in the aqueduct between Ashokan and Kensico reservoirs. Basic filter alum is added at Pleasantville, two miles above Kensico. This produces a jelly in the water entangling the turbidity so that it settles out in the upper part of Kensico, chiefly in the first half mile. The highest dosage used has been 1.6 grains per gal. for 300 p.p.m. of turbidity. The lowest dosage is about 0.35 grain per gal. for 10 p.p.m. of turbidity. Sufficient lime hydrate is also added to neutralize the slight acidifying effect of the alum. The amount of lime used is one-quarter to one-fifth the amount of alum used. The purpose is to return the water as nearly as possible to its

condition before the addition of alum. In 1937, there were used 3,517 tons of alum, 711 tons of lime hydrate and 24 tons of soda ash. Treatment took place from March 1 to May 20 and from November 3 to December 31. The turbidity treated ranged from 50 to 7

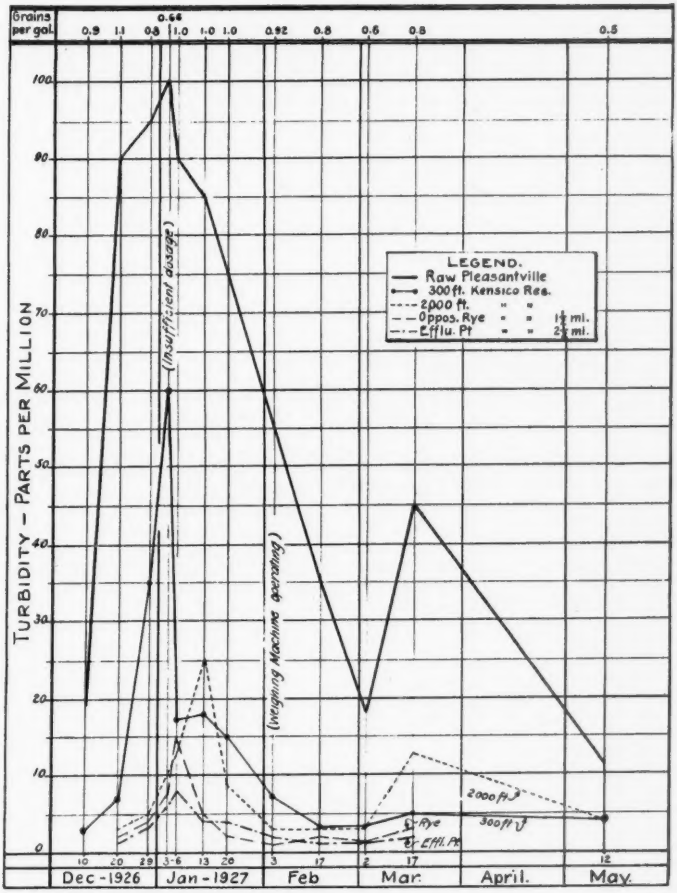

FIG. 6.—REMOVAL OF TURBIDITY IN KENSICO RESERVOIR AFTER ALUM TREATMENT AT PLEASANTVILLE.

p.p.m. and the turbidity of the settled water as it left Kensico Reservoir was only 4 to 1 p.p.m. Dosage of alum ranged from 0.7 to 0.45 grains per gal. with an average of 0.58 grain. The average dose of lime hydrate was 0.12 grain per gal.

The fact that the Catskill water was likely to become turbid was known for several years before turbidity occurred in the water. The necessary treatment was also planned by the Laboratory Division several years before this first experience even to the extent of the dosage required. Treatment was first needed in the winter of 1926-1927. Figure 6 shows the amount of turbidity in the water entering Kensico Reservoir and its decrease at various points down through the reservoir to the effluent. During treatment, daily samples are taken to Mt. Kisco Laboratory for special tests, so chosen as to show whether dosage is effective. Also at regular intervals, samples are taken down through the reservoir from top to bottom to show the extent to which settling of the turbidity is taking place. At the request of the Laboratory Division and as a result of previous experience and large-scale experiments, a new plant has been built this year at the head of Kensico Reservoir for the addition of lime. It is expected that there will be a saving in the dosage of alum at the Pleasantville plant of at least 20%, since a lower dosage forms a better floc if alum is added some time prior to the addition of lime.

Iron Removal. Numerous well supplies contain iron held in solution by carbonic acid gas. The water is clear as it leaves the well but settles out iron oxide upon standing. To remove this iron from the well water, several plants are operated by the Department and by the private water companies. Usually, the water is aerated to remove carbonic acid and introduce oxygen so that the iron will settle out. The Department owns plants at Jameco and Springfield pumping stations and a new type of plant at Flushing pumping station. At this last plant lime is added to the water to remove the carbonic acid and there is no aeration. The iron is removed as ferrous carbonate, and the water after filtration enters the main free from carbonic acid gas and dissolved oxygen and hence is non-corrosive. The Long Island Water Corporation has a plant at Valley Stream, the Roxbury Company at Roxbury, the New York Water Service Corporation at Flatbush Well 25, and the Jamaica Water Supply Company at Wells 6, 18 and 24. Sand filters exist at all plants except at Well 24. The plant

at Well 18 is of novel nature, the water being aerated under pressure and passed through a mixture of sand and pure calcite of sand size.

Microscopic Organisms. Floating microscopic organisms occur in the reservoirs. These are minute plants, many of which produce essential oils similar to those of flowers. These oils cause taste and odor in the water supply. For example fishy tastes are due to protozoa and other organisms and not to fish. These growths are controlled by treatment with copper sulphate, increased amounts of chlorine, change in points of draft, particularly from surface to deep water, etc. Some of the more commonly occurring organisms that have caused trouble in New York City's supply are: The diatoms *Asterionella* and *Tabellaria* which produce geranium to fishy odors; the cyanophyceae *Anabaena* and *Aphanizomenon* which produce grassy to pigpen odors; protozoa *Uroglena* which produces oily and fishy tastes, *Synura* which produces cucumber and bitter tastes, and *Dinobryon* which produces fishy odors; and the schizomycetes *Crenothrix* which clogs well systems. Temperature is one of the most important controlling factors in the development of these organisms. Diatoms appear most frequently in the spring and fall and cyanophyceae (blue-green organisms) in the hot summer season.

The most common method of treatment with copper sulphate is to drag the chemical in burlap bags through the water, suspending the bags over the side of a boat. Rowboats are used for small reservoirs and launches for large reservoirs. The chemical is stored in a bin in the center of the launch and shoveled systematically into bags suspended on either side. The rapid motion of the boat and the churning effect of the propellor mix the chemical with the water rather thoroughly. The amount of chemical for each portion of a large reservoir is based upon the total volume in that portion. The path of the boat follows parallel courses and then courses at right angles until the whole surface area has been covered and the amount of chemical for the particular area supplied. Even such a large reservoir as Kensico has been entirely treated many times. Occasionally, when a distribution reservoir in the city may not be taken out of service, it has been successfully treated by applying the chemical to the upper half or two-thirds of the reservoir. This has been done in Central Park Reservoir where it takes a week or ten days for the entire volume of water to be displaced. The treated water displaces the untreated

water, and the effect of treatment is usually evident in about a week. Table 7 illustrates the results obtained.

TABLE 7—COPPER SULPHATE TREATMENT OF THE UPPER HALF OF CENTRAL PARK RESERVOIR

Date	*Asterionella* Standard Units per c.c.	Total Organisms Standard Units per c.c.
April 15, 1926, before treatment	1,150	2,040
April 22, 1926, 3 days after treatment	1,350	2,100
April 29, 1926, 10 days after treatment	370	500

On December 30, 1919 a new method of treatment was started. On the Catskill Aqueduct between Ashokan and Kensico reservoirs, a plant built by the Board of Water Supply, at Pleasantville, for the purpose of adding alum for turbidity treatment, was used to feed dry copper sulphate continuously to the water in the aqueduct. The flow of water is definitely known as it is measured by Venturi meters. Strange to say, the effective dosage for various organisms was found to be the same as that needed when the chemical is added to the reservoir.

More recently, continuous treatment has been applied to Croton Lake at Muscoot Dam. At this plant about 300,000 g.p.d. of water are pumped from the lake, passed through a baffling chamber to which copper sulphate is dry fed. The resulting solution is then passed to a 6-in. wood-stave pipe 1000 ft. long that is attached to the back of Muscoot Dam a foot or two below the surface of the water. Brass injectors at four-foot intervals mix the solution with the water. General dosage has been 1.5 lb. per m.g. The treatment has been eminently successful, frequently reducing taste-producing organisms by 100% and decreasing by about 50% the yearly average number of total organisms that reach the distribution system in the city (Tables 8 and 9).

Fortunately, chlorine also is useful in controlling microscopic organisms, in some cases destroying those organisms that are not acted upon by copper sulphate. When chlorination of the effluent of Ashokan Reservoir was introduced, the use of copper sulphate in the Catskill Aqueduct was rendered unnecessary most of the time. In

TABLE 8—COPPER SULPHATE TREATMENT OF CROTON WATER AT MUSCOOT DAM
(Week ending August 5, 1933)

Organism	Standard units per c.c. Woods Bridge*	Screen Chamber**
Asterionella	25	—
Melosira	175	present
Synedra	35	150
Tabellaria	120	—
Anabaena	1075	—
Aphanizomenon	575	present
Clathrocystis	275	—
Coelosphaerium	100	—
Ceratium	present	—
Peridinium	present	—
Total	2380	150

*Taste-producing organisms 2170, before treatment.
**Taste-producing organisms—none. Point of draft about 10 miles below Woods Bridge.

TABLE 9—MICROSCOPIC ORGANISMS—STANDARD UNITS PER C.C.

Year	Muscoot Reservoir	Croton Lake Effluent	Percentage Reduction
No treatment			
1928	1160	840	28
1929	1300	775	40
1930	1520	790	48
With treatment			
1931	1535	425	72
1932	1670	340	80
1933	1900	410	78

the winter of 1921-1922, *Synura* occurred in both Ashokan and Kensico reservoirs, and the formation of ice prevented reservoir treatment. Recourse was had to chlorine to control this growth in the aqueduct, and it was then learned that not only would the chlorine destroy the organism, but it would, in many instances, destroy the disagreeable taste or odor as well. In 1938, 105 tons of copper sulphate were used in the control of microscopic organisms. If properly applied, copper sulphate very rarely causes the death of many fish. Table 10 has been published as indicating the limiting dosages that may be applied without killing the fish named.

TABLE 10—LIMITING SAFE DOSAGE OF COPPER SULPHATE FOR FISH

Fish	Parts per million	Pounds per million gallons
Trout	0.14	1.2
Carp	0.33	2.8
Suckers	0.33	2.8
Catfish	0.40	3.5
Pickerel	0.40	3.5
Goldfish	0.50	4.2
Perch	0.67	5.5
Sunfish	1.35	11.1
Black bass	2.00	16.6

Judging from experience obtained at the San Francisco World's Fair, where copper sulphate failed to kill troublesome carp, the table applies to waters that are not sufficiently hard quickly to precipitate the copper as carbonate.

Laboratory Division. This Division operates three laboratories: Mt. Prospect, Mt. Kisco, and Ashokan. Mt. Prospect Laboratory

FIG. 7.--MT. PROSPECT LABORATORY, THE CENTRAL LABORATORY OF THE DIVISION OF LABORATORIES.

(Fig. 7) is located in the city, the other two on the Croton and Catskill watersheds respectively. All sources of supply are regularly analyzed. These analyses cover physical, chemical, bacteriological and microscopical examinations. Daily analyses from the physical and bacteriological standpoint are made at many points, particularly at certain taps in the city, the large chlorination plants and one of the sewage disposal plants. During 1939, 31,444 samples were analyzed. The force includes eight chemists, five bacteriologists, five laboratory assistants, five clerical services and six laborers. In addition, one laborer is loaned regularly at the Ashokan Laboratory. To summarize, the Laboratory Division exercises analytical control of chlorination plants, sewage disposal plants, iron removal plants, turbidity removal, removal of microscopic organisms, and general sanitary condition of the water supply. Standards for determination of residual chlorine are maintained at the chlorine plants, and twice a year dosage is checked at the larger plants by determination of chlorine absorption by the raw water supply. At the sewage disposal plants, the efficiency of each step in the process is determined by analysis. This is also true of the iron removal plants. Practically all water work is performed for other city departments, including the Department of Health, Board of Education, Department of Parks, etc. This centralizes the work with economy and protects the health of the people through analysis of swimming pools and beach waters in addition to drinking water.

New mains that are laid are chlorinated, and samples are analyzed to ascertain the results. In 1939 189 reports were made. The 72-in. pipeline on Long Island was not put into service after reconditioning until it was approved by this division.

The Laboratory Division also makes independent inspections. In 1939, there were 59 such inspections, including 45 tests of chlorine plants. These inspections were made in connection with sanitary conditions on the watersheds, sewage disposal plants (operation and construction), chlorination control and efficiency (including absorption tests, fixation of dosage, comparison of standards, condition of machines, and protection against leaks), turbidity control of the Catskill water and Long Island water (including accumulation of sludge in Kensico Reservoir and new line treatment plant for Catskill aqueduct), shaft and tunnel construction for new Delaware development,

problems of corrosion and its prevention, reservoir treatment for microscopic organisms, occurrence of *B. coli,* operation of new wells of private water companies, annual survey of well systems of the Jamaica Water Supply Company and of the Flatbush and Woodhaven territories of the New York Water Service Corporation, iron removal plants, complaints of quality of water and sickness, sanitation of park areas on water supply lands under control of the Long Island State Park Commission (in connection with horseback trails and swimming), industrial problems, new laboratory plans, water sampling points, death of fish, operation of upstate laboratories, prevalence of seagulls on the reservoirs, and control of boiler waters.

Research on various problems is carried on by this Division, and advice is given on various engineering problems such as plans for iron removal plants and sewage disposal works. One subject of research that has extended over many years has dealt with the causes of corrosion by the various water supplies of pipes of different materials and with possible means of corrosion prevention.

BACTERIOLOGICAL AND FIELD STUDIES OF WATER DISTRIBUTION SYSTEMS

BY WARREN J. SCOTT*

[*Read September 26, 1940*]

The discrepancy in the bacteriological results of samples collected near points of water treatment on public water supplies in Connecticut and samples obtained at various points throughout distribution systems led the Connecticut State Department of Health to conduct a study of conditions in three distribution systems over a period of a year. This discrepancy had been noted particularly in surface water supplies derived from relatively clean watersheds, free from known sewage discharge, and treated only by chlorination. In order to secure a cross-section of several conditions, three somewhat different types of systems were studied. For the purpose of discussion these systems are referred to as those of Town A, City B, and City C. The field work was carried out by Eugene L. Lehr, Senior Sanitary Engineer, and David C. Wiggin, Assistant Sanitary Engineer, under the direction of the author.

Description of Supplies. The supply of *Town A* is derived from a watershed free from permanent habitations and regularly inspected. (Fig. 1) As for all surface water supplies, there is, of course, opportunity for chance contamination. The watershed area is approximately 3.4 sq. miles. The one storage and distribution reservoir has an estimated capacity of 60 m. g. Water is furnished by gravity to about 3,500 persons. There are no large industrial consumers, nor are there any known cross-connections in the system. The average daily consumption is about 300,000 gal. There is no storage on the distribution system. The source of supply and the chlorination plant are distant about 4.5 miles from the main distribution system. Water is treated by means of a chlorinator of the automatic type, variations in dosage being accomplished by effect of varying heads through an orifice set in the line. While the chlorinator has a wide range of dosage, information obtained led to the belief that on some occasions

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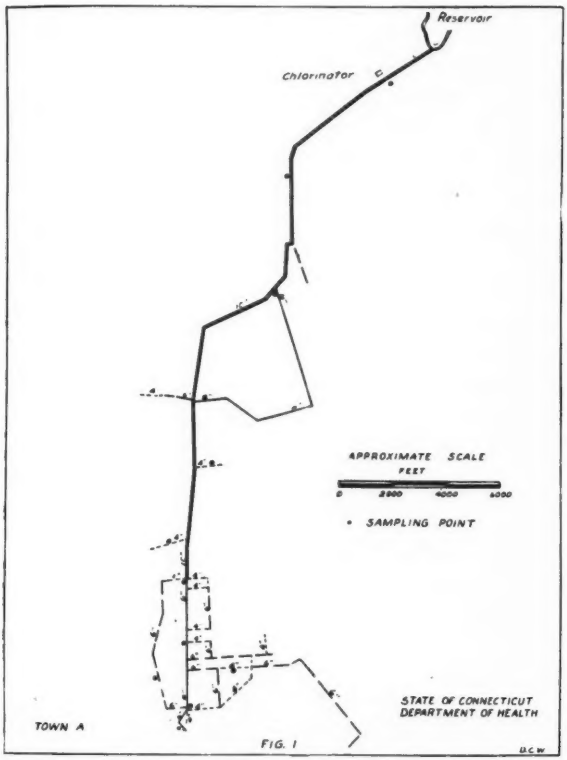

FIG. 1.—WATER SUPPLY OF TOWN A.

during the year when the orifice meter was registering a maximum flow on the chart, higher flows were actually taking place than were being registered and the chlorine dosage was inadequate, even though this occurrence was not actually observed at the times of inspections. On a small system of this type, opening of several hydrants produces a flow out of all proportion to the normal variations in consumption. The water is of moderate color and relatively soft. The ammonia content is low.

City B (Fig. 2) is supplied by two systems known as the low-service and high-service systems. The study was confined to the

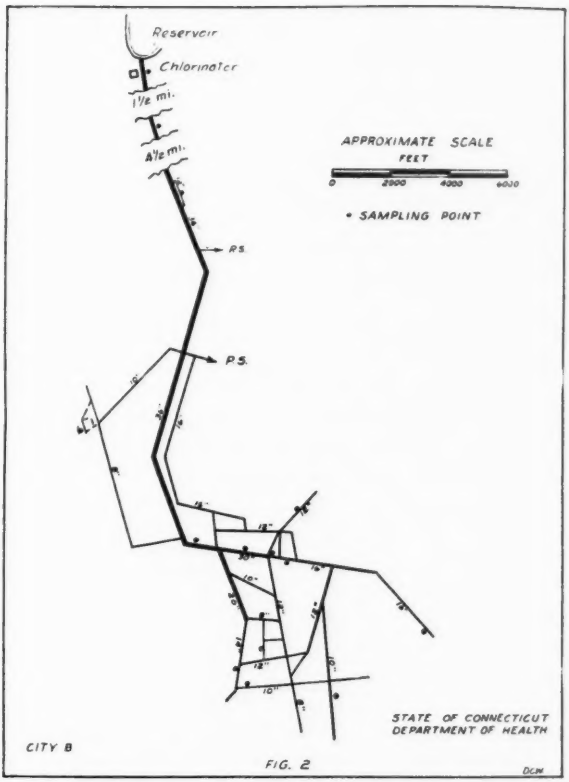

FIG. 2.—WATER SUPPLY OF CITY B.

low-service system which is the principal supply. The low-service supply is derived from a watershed of 18 sq. miles, occasionally reinforced by diversion from another watershed of 37 sq. miles. The lower distribution reservoir has an estimated capacity of 735 m. g., and an upper reservoir has an estimated capacity of 2 billion gal. Water flows to the distribution system by gravity through a long pipe line, and the main part of the distribution system is situated about 10 miles from the supply reservoir and treatment plant. Water is treated near the reservoir by automatically controlled, Venturi-oper-

ated chlorinators, and the range of chlorinator capacity appears to be adequate to care for all flow variations encountered. There is practically no storage in the distribution system except in one or two small, outlying, high-pressure districts to which water is pumped. These small districts did not affect the study. The entire supply of the city furnishes water to approximately 100,000 persons, and the average consumption is about 10.4 m. g. d. The watersheds are regularly inspected by the State Department of Health at approximately annual intervals, and more frequent inspections are made by the city. All habitations on the watershed are checked as to sanitary conditions. The watershed may be considered as relatively clean and is free from any known sewage discharge. The city has many large industrial consumers, and careful checks of cross-connections have been carried out. Several industrial cross-connections are protected by double check-valves of approved type, regularly inspected and tested by the State Department of Health. It is not believed that

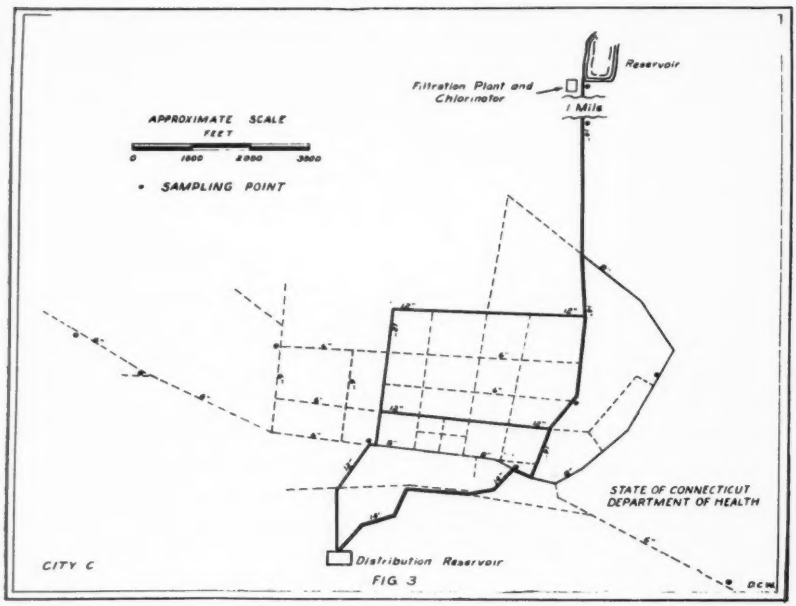

FIG. 3.—WATER SUPPLY OF CITY C.

cross-connections are responsible for any of the conditions noted. The water is of moderate color and is relatively soft. The ammonia content is low.

The supply of *City C* is obtained from a reservoir located on a river with a drainage area of about 162 sq. miles. Despite the size of this watershed, there are no public sewerage systems nor known places of sewage discharge. The watershed is regularly inspected as to sanitation. The reservoir has a capacity of approximately 125 m. g. Water is pumped from the reservoir through low-lift pumps to a modern, rapid, sand filtration plant where the treatment consists of aeration, coagulation with alum and soda ash, sedimentation, rapid sand filtration, ammoniation, chlorination, activated-carbon treatment, and occasionally pre-chlorination. Filtration was installed primarily to reduce color and objectionable tastes and odors noticeable in the untreated water. From the filtered-water basin, high-lift pumps discharge the treated water directly to the distribution system, about two miles away, the surplus rising to an open, elevated basin situated in an isolated area and having a capacity of about 5 m. g. This elevated reservoir feeds the system when the pumping station is not in operation. The population supplied is approximately 12,500 persons, and the average daily consumption is about 900,000 gal. The city is an industrial community. The conditions with reference to cross-connections are similar to those described under City B.

Method of Survey. Each supply was visited by a sanitary engineer of the State Department of Health one day a week over a period of a year. Four samples of untreated water were collected, two in the morning and two in the afternoon. Residual chlorine tests were carried out at the point of chlorination during each morning and each afternoon of the day of visit. Tests for interfering substances were made, and interference was allowed for in the residual chlorine tests. The residual chlorine tests allowed a ten minute contact with the disinfectant in the case of Town A and City B. In City C, where chlorine and ammonia were used, the chloramine tests were made after two-hour contact. The chlorine dosage and operation were checked. If the chlorine dosage was inadequate, the dosage was changed. Effort was made to maintain a chlorine residual of at least 0.2 p.p.m. in Town A and City B, and, in the former, the chlorine residuals fre-

quently ran above this figure. In City C, the chloramine residuals were usually maintained at about 0.35 p.p.m.

Samples for bacteriological examination were collected on each day of visit at a number of points throughout the distribution system. Figures 1, 2, and 3 show the relation of the distribution systems to the sources of supply and indicate the approximate locations of sampling points. Effort was made to locate the sampling points in the distribution systems so as to get a fairly accurate picture of conditions. In Town A, there were nine sampling points; in City B, there were thirteen points; and in City C, there were nine points. These do not include points directly below the points of chlorination which were also sampled on each day of visit. At the times of collection of all samples, residual chlorine tests were made at the sampling taps. Also, water temperatures were recorded.

Where residuals were noted, the samples in the bottles were neutralized with sodium thiosulphate except in City C where chloramine residuals were constantly present throughout the distribution system. In City C, some of the samples were neutralized and some were not.

Rainfall and Temperature. Figures 4, 5 and 6 show, for the three communities, the variations in rainfall and temperature as they relate to the color of the water and the chlorine dosages (or chlorine demands). Several heavy rainfalls occurred during the period of the surveys. Probably the most significant occurrence was the extremely heavy rainfall on the watershed of City B. Here a rainfall of 3.48 in. in one day was followed two days later by a rainfall of 4.35 in. The effect of this rainfall on the chlorine demand of the water and the bacteriological results is discussed later. The rainfall was fairly generally distributed throughout the year.

There did not appear to be any direct correlation between temperatures and chlorine dosages. In the course of these studies, it was noted that the bacteriological condition of the treated waters was poorer during that part of the year when water temperatures were generally above 50° F.; but other factors, such as interruption of chlorination, were in part responsible so that it is not felt that any definite conclusions could be drawn as to temperature effects on treatment and water quality. Water temperatures ranged in Town A from 38 to 78° F., in City B from 33 to 75°F., and in City C from 34 to 78° F. These are indicated in Figures 4, 5 and 6. It was found that

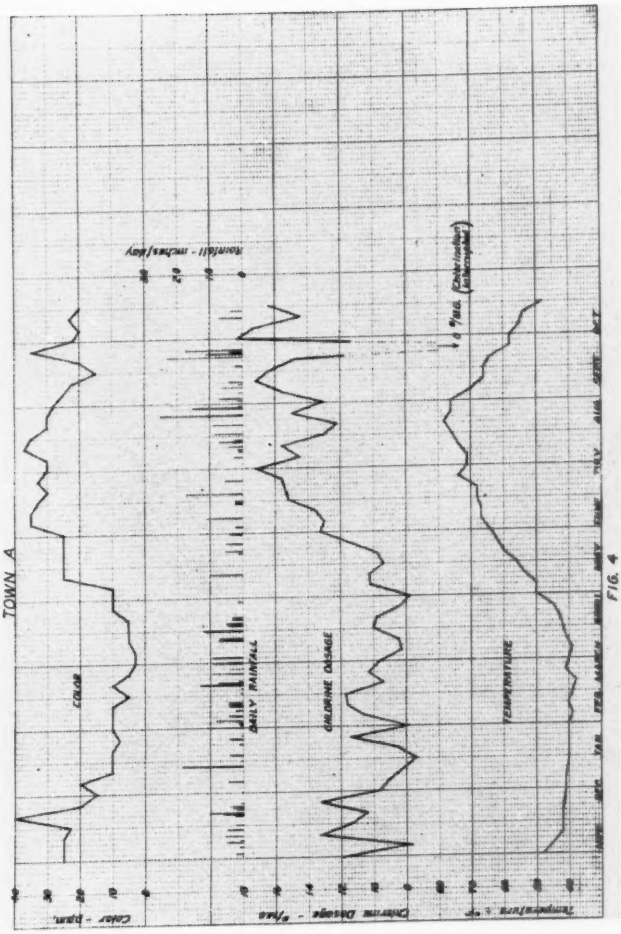

FIG. 4.—RAINFALL, TEMPERATURE, COLOR AND CHLORINE DOSAGE—TOWN A.

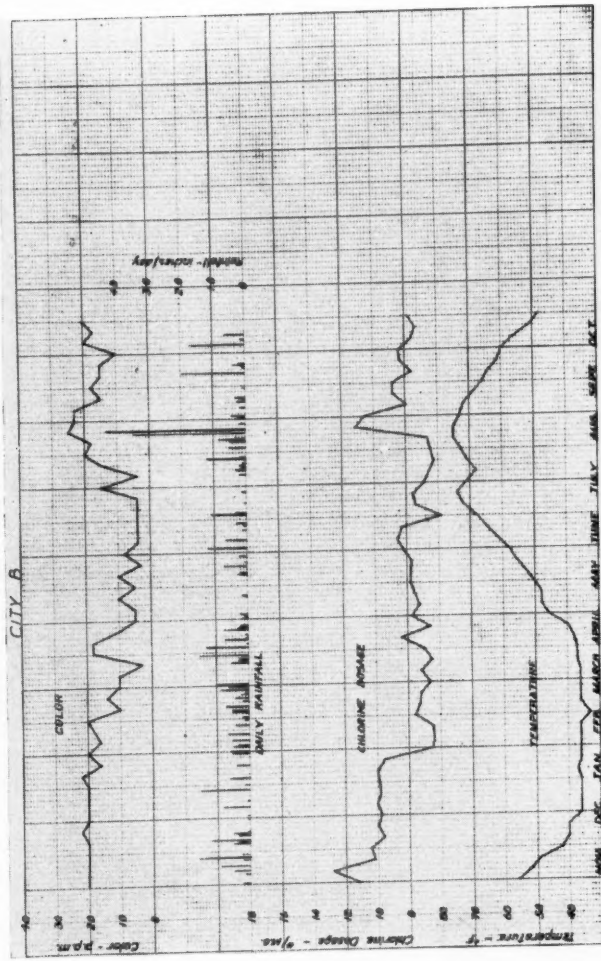

FIG. 5.—RAINFALL, TEMPERATURE, COLOR AND CHLORINE DOSAGE—CITY B.

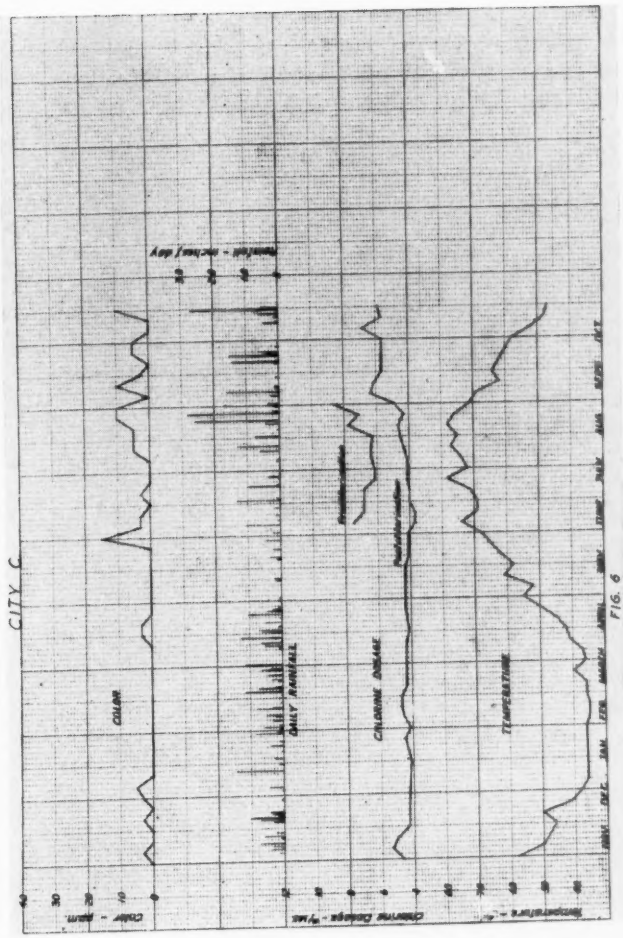

FIG. 6.—RAINFALL, TEMPERATURE, COLOR AND CHLORINE DOSAGE—CITY C.

temperatures varied as much as 12° F. at times, notably in the winter and summer, between the water as it entered the distribution system and as it was delivered at remote parts of the system.

Bacteriological Quality of the Untreated Waters. With further reference to the effect of run-off and temperatures upon the water supplies, Figure 7 is of interest in presenting the variations in the bac-

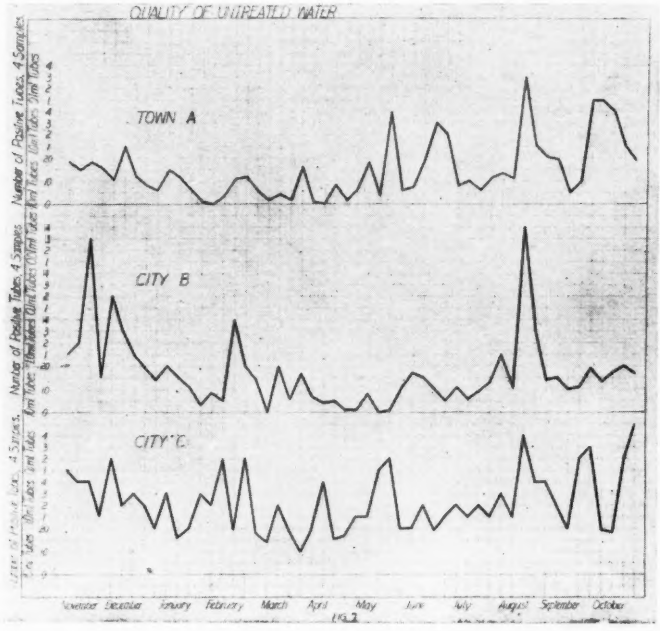

FIG. 7.—NUMBER OF TUBES POSITIVE FOR COLIFORM ORGANISMS.

teriological quality of the untreated waters. This figure was prepared without any attempt to establish a rational basis of probable content of coliform organisms but is simply a pictorial tabulation which the author believes is easier to follow. Each sample was examined according to the methods outlined in "Standard Methods of Water Analysis". Five 10-c.c. portions were run on each sample, and on the untreated water one tube was run on the greater dilutions down to

0.001-c.c. As there were four samples of the untreated water, there were twenty 10-c.c tubes, four 1.0-c.c. tubes, etc., each day for each supply. Certain anomalous results were obtained, where for example no growth was found in 1-c.c. but a positive growth in 0.1-c.c. These were recessed along the lines of recessing oyster scores, in order to obtain a quick simple picture with relatively slight error so far as interpretation of results is concerned.

It is of interest to note that in Town A the winter and spring samples of untreated water were consistently of fair quality and that in City B the untreated water was of fair quality during the spring and summer until late summer rains fell. During the remaining periods, the untreated waters of both Town A and City B varied considerably in quality. In City C, where the water is derived from a large watershed, the quality of the untreated water varied considerably during the entire year. As examples of the variations: in Town A, on two days the untreated water showed no coliform organisms in 10-c.c. portions, whereas on at least one day three of four samples showed coliform organisms in 0.1-c.c. portions; in City B, the quality of untreated water samples ranged from no coliform organisms in 10-c.c. on one day to coliform organisms down to 0.01-c.c portions in four samples on another day; in City C, the untreated water samples always showed some contamination, varying over a wide range.

Bacteriological Research Studies. At this point, before proceeding to discuss the bacteriological quality of the treated water, reference should be made to the bacteriological research studies carried out by the Bureau of Laboratories of the Connecticut State Department of Health under the direction of Dr. F. L. Mickle. The author, in this paper, will refer to the laboratory studies but briefly. The detailed results are being presented before the Laboratory Section of the A.P.H.A. at Detroit by Mr. Earle K. Borman and Miss Elizabeth D. Robinton, respectively Assistant Director and Senior Microbiologist of the Bureau of Laboratories, and Professor Charles A. Stuart, Professor of Bacteriology at Brown University, who cooperated.

One of the reasons for making the studies was to obtain information to correlate field survey conditions and results of laboratory bacteriological analysis. There has always been some difference of

opinion as to whether the methods set forth in "Standard Methods of Water Analysis" should be strictly adhered to or whether an equally fair picture of the condition of the water is obtained by a modification of "Standard Methods". In Connecticut, some modifications have been tried out, particularly the discarding of lactose broth tubes that show very little gas formation, the elimination from consideration of atypical colonies on eosine-methylene-blue agar, and the discarding of confirmatory lactose broth tubes, fished from colonies on eosine-methylene-blue agar, which showed no gas in 24 hours. All samples collected were examined both according to *strict* interpretation of "Standard Methods" and by a so-called "Modified Method", in order to get comparative data. The laboratory also carried out special investigations of identification of the types of coliform bacteria found. In all analytical data discussed in this paper except where specifically

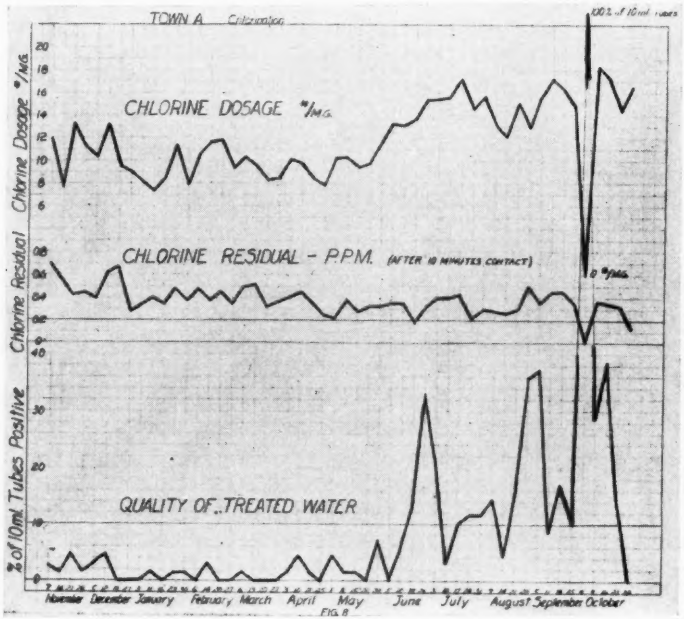

FIG. 8.—CHLORINE DOSAGE AND RESIDUAL AND PERCENT OF POSITIVE 10-ML. TUBES—TOWN A.

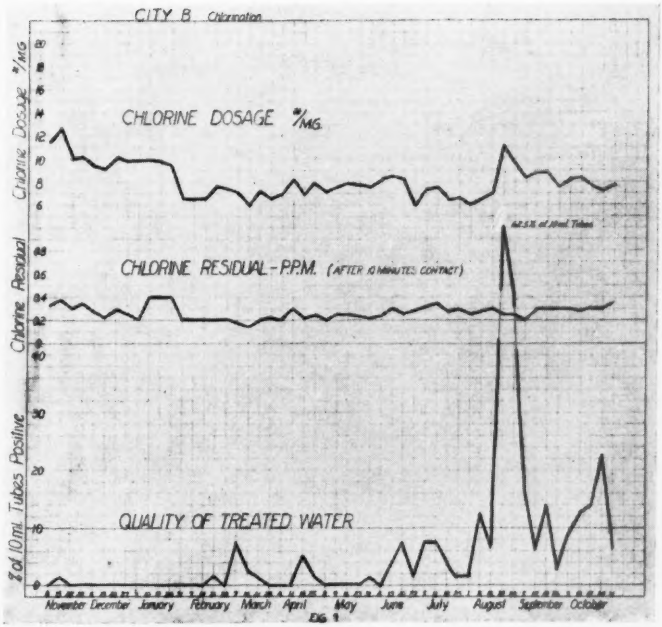
CITY B. Chlorination
CHLORINE DOSAGE #/MG.
CHLORINE RESIDUAL - P.P.M. (AFTER 10 MINUTES CONTACT)
QUALITY OF TREATED WATER
Chlorine Dosage #/MG.
Chlorine Residual
% of 10 ml. Tubes Positive
November December January February March April May June July August September October

FIG. 9.—CHLORINE DOSAGE AND RESIDUAL AND PERCENT OF POSITIVE 10-ML. TUBES—CITY B.

mentioned, the analytical reports are on the basis of examinations according to "Standard Methods".

Bacteriological Quality of the Treated Waters. Figures 8, 9 and 10 are charts showing for each of the three supplies, the relationship of and variations in chlorine dosage, chlorine residual, and quality of treated water throughout the survey. While the charts indicate poorer bacteriological quality in the summer and fall months, inadequacies in water treatment were also involved during some of this period, and another similar study might not check the trends shown. This has already been referred to under "Rainfall and Temperature".

In Town A, the samples of treated water for the yearly period did not quite meet the United States Treasury Department standard of bacterial quality with regard to the percentage of samples that

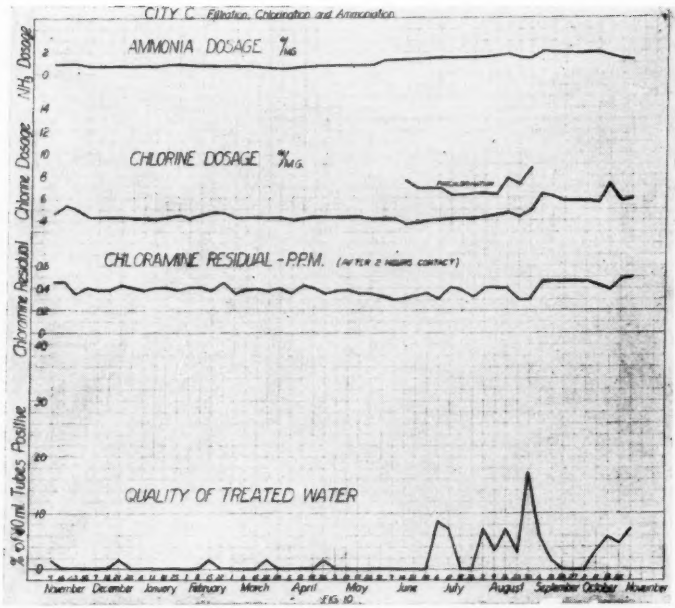
CITY C. Filtration, Chlorination and Ammoniation
AMMONIA DOSAGE
CHLORINE DOSAGE
CHLORAMINE RESIDUAL - P.P.M.
QUALITY OF TREATED WATER
NH3 Dosage
Chlorine Dosage
Chlorine Residual
% c/40 ml Tubes Positive
November December January February March April May June July August September October November

FIG. 10.—CHLORINE AND AMMONIA DOSAGE AND CHLORAMINE RESIDUAL AND PERCENT OF POSITIVE 10-ML TUBES—CITY C.

showed coliform organisms in three out of five 10-c.c. portions (5% maximum). For the yearly period, however, the supply would meet the requirement of this standard relative to the maximum permissible percentage of positive 10-c.c. tubes (10%). The yearly totals were greatly influenced by complete interruption of chlorination on one day. The effect of this and other factors on the supply of Town A are discussed later. It is noted that for about one-third of the time the samples for one particular day did not meet the U. S. Treasury Department standard.

In City B, the treated water over a yearly period met the U. S. Treasury Department standard of bacterial quality. This was also true of City C. In City C, where the supply is filtered, ammoniated, and chlorinated, by far the best results were obtained. In City B, on eight days out of fifty-two, the supply failed to meet the maximum

allowable percentages of positive samples permitted by the U. S. Treasury Department standard even though the yearly total did. In City C, on only one day did the supply fail to meet the U. S. Treasury Department standard. When mentioning these daily figures in reference to the standard, it should be stated that this applies only to the *figures* of the standard and not to the standard itself, in that the standard is based on samples that are taken over a considerable period of time.

It has been mentioned that City B and City C met the U. S. Treasury Department standard for bacterial quality over a year's period and that Town A, in the same time, failed to meet the standard in one respect, although nearly up to requirements. Using the so-called "Modified Method" of analysis referred to, all three supplies met the figures in the standard. Two or three pertinent comments come to mind. One is that in the author's experience the water laboratories whose methods *strictly* adhere to the methods prescribed in "Standard Methods of Water Analysis" are few and far between. For the sake of gathering more information on compliance with the standards, it is unfortunate that there is not more strict adherence. Many laboratory reports are not comparable. Another thought is that the figures set forth in the U. S. Treasury Department bacteriological standard are subject to a wide variety of interpretations in that no time limit is specified for the maximum allowable percentages of positives. Supplies examined infrequently may fail to meet the standard, but if examinations are increased in number temporary occurrences of poor quality may be glossed over by grouping poor samples with series of good samples. The choice of sampling points is another important factor. It does not appear to be fair, in making comparisons, to collect samples in one case from the treatment plant alone and in another from both the treatment plant and the distribution system, samples from which are likely to be poorer.

Comparisons between tabulations of laboratory reports of (1) samples collected immediately below the points of treatment on the three supplies and (2) samples collected from the distribution systems gave information that was of interest. In general, it may be stated that the samples collected immediately below the points of treatment were satisfactory and that the results of the analyses complied easily with the U. S. Treasury Department standard on all three

supplies. This statement also applies to those samples collected just below the points of treatment and immediately neutralized with sodium thiosulphate. On the supply of City C, in which chloramine residuals were present over much of the distribution system, there was a tendency toward somewhat poorer samples at the dead ends of the system, although even there the samples were well within acceptable limits. On the supply of Town A, the samples from the ends of the distribution system were much poorer than the samples just below the point of treatment. The poorest results were obtained at the most remote point of the distribution system where the water had been in contact with the mains for at least 4 or 5 hours according to theoretical calculations. In City B, the breakdown of the results of analyses of samples from different sampling points did not indicate such a marked difference as in Town A. However, the samples from three of the more remote points on the distribution system in City B, were noticeably poorer than those from other points in the distribution system. Even though the supply as a whole would readily meet the U. S. Treasury Department standard, these three remote sampling points grouped together and summarized would not meet the standard. Possible partial explanations for some of the analytical results for the supplies of Town A and City B are discussed elsewhere in this paper, particularly with reference to lack of adequate chlorine residuals. Some of the poor analytical results on the supply of City C cannot be readily explained, although they are possibly influenced to some extent by the effect of the open equalizing reservoir on the distribution system.

Chlorine Dosage. The chlorine dosages are, of course, measured by the chlorine demand of the water. The variations in chlorine dosages shown in Figures 8, 9, and 10 are of interest, the dosages being governed by the ortho-tolidin tests for chlorine residuals. In Town A, higher dosages were necessary in the summer, while in City B, dosages in the late fall and early winter were highest. The charts indicate the wide range in the chlorine demand of different waters. For example, in Town A, the chlorine dosage ranged from 7 to 18 lb. per m. g., nearly a 1 to 3 ratio, and in City B, there was a similarly wide range of from 6 to 13 lb. per m. g. A striking increase in chlorine demand was noted in City B after an extremely heavy run-off. During a period of three hours the chlorine dosage had to be increased from a rate of

7 lb. per m. g. to 11 lb. per m. g. The poor bacteriological results in the distribution system of City B after this heavy rain suggest that the speed of adjustment of the chlorine dosage did not keep pace with the increase in chlorine demand. This is despite the fact that all reasonable efforts were made to increase the chlorine dosage promptly and is an indication of the difficulty of adjustment of chlorine dosage at times of heavy run-off on unfiltered surface water supplies even though frequent ortho-tolidin tests are made.

In City C, where chlorine and ammonia were both applied to a filtered water, the chlorine dosage varied from 3.5 to 7.5 lb. per m. g. Pre-chlorination was used at the filtration plant of City C for a few weeks to improve odor and taste conditions. It is to be noted that the filter plant in City C evened out peaks of change in chlorine demand as contrasted with the two unfiltered supplies.

Chlorine Residual. In Town A, as has been mentioned, the chlorine residual just below the chlorinating plant usually ranged considerably above 0.3 p.p.m. after a 10-minute contact. In City B, the chlorine residual was kept close to 0.2 p.p.m. with a range between 0.15 and 0.4 p.p.m., although at the time of heavy rainfall in August the residual evidently disappeared before the dosage was changed. This happened between the times of our inspections. In City C, the chloramine residual after a 2-hour contact was maintained at about 0.35 p.p.m. on the average and ranged from 0.3 to 0.5 p.p.m.

In Town A, chlorine residuals were noted along the distribution system to a distance of about 1½ miles below the point of chlorination. In City B, a chlorine residual was noted generally at a point 7½ miles below the point of application of chlorine and occasionally as far as 10 miles below this point. It is of interest to note that in Town A the theoretical time for the water to traverse 1½ miles is about 2 hours, and in City B the time to traverse 7½ miles is about 4 hours. In City C, chloramine residuals were generally found throughout the distribution system in varying amounts, except that at the very ends of the distribution system there was no chloramine residual.

After-Effects of Chlorination Interruption. While not scheduled as part of this study, complete cessation of chlorination for a day on the supply of Town A, due to trouble with the chlorination apparatus gave a very informative picture of the results of such happenings on the quality of the water in the distribution system. Perhaps the best

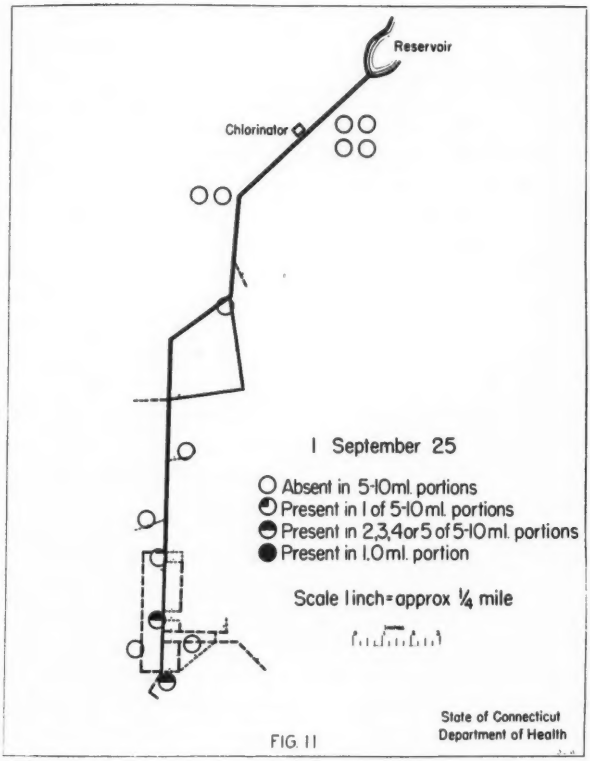

FIG. 11.—BACTERIOLOGICAL RESULTS OBTAINED DURING WEEK PRECEDING BREAKDOWN OF CHLORINATOR.

way to indicate the results is by plotting them (Figs. 11 to 16). The analytical results shown in these plots represent a series of samples taken during six successive weeks. In Figure 11 the samples were obtained during the week prior to the chlorinator breakdown. In Figure 12 the samples were collected just during and after the chlorinator breakdown. It will be noted that following a complete blackout of the map with poor samples there was a slow but gradual improvement, starting near the point of treatment, and following along

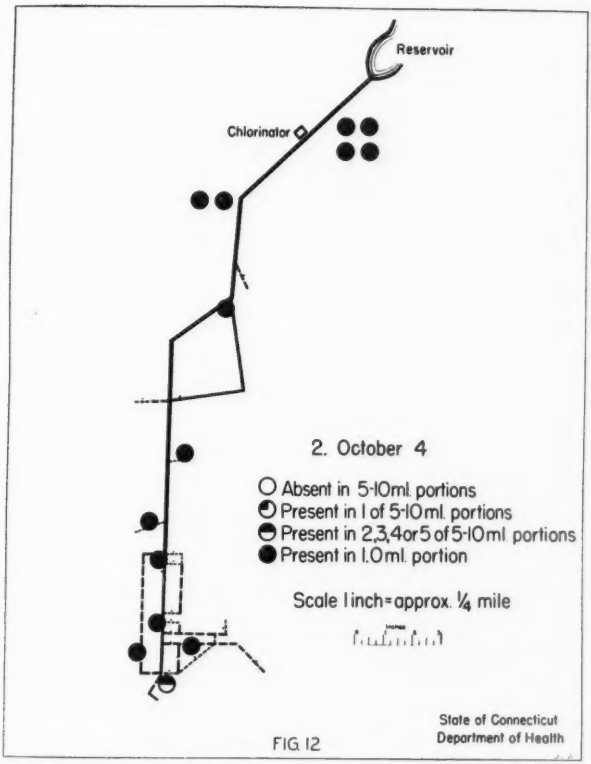

FIG. 12.—BACTERIOLOGICAL RESULTS OBTAINED DURING AND JUST AFTER BREAKDOWN OF CHLORINATOR.

the distribution system until the entire system had recovered four weeks later.

On the supply of City B, while the chlorinator did not break down, a similar effect on the distribution system was produced after a sharp increase in chlorine demand following a cloudburst of heavy proportions. This undoubtedly permitted inadequately chlorinated water to enter the distribution system. The following results were obtained in City B:

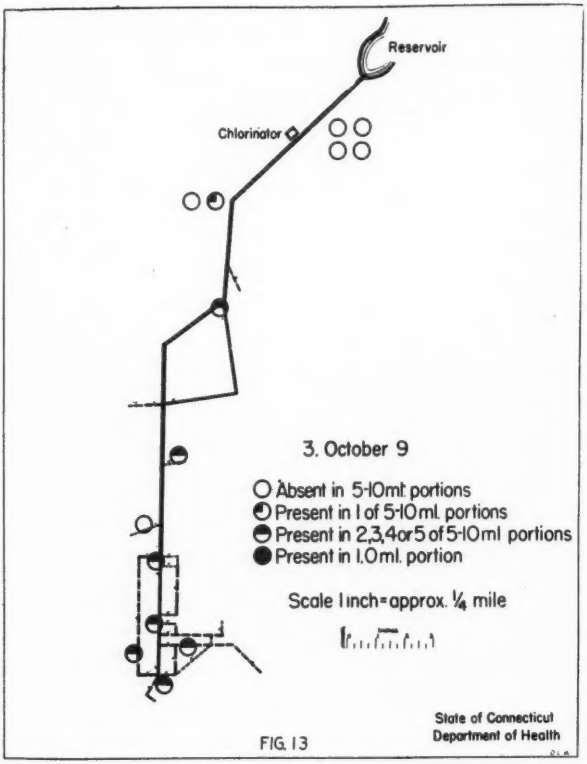

FIG. 13.—BACTERIOLOGICAL RESULTS OBTAINED DURING FIRST WEEK FOLLOWING BREAKDOWN OF CHLORINATOR.

Date	Percentage of positive 10-c.c. tubes (10% maximum desirable)
August 15	7
August 22	62.5 (after heavy rains)
August 29	50
September 5	17
September 12	6

Here again it will be noted that not until three weeks after the entrance of a considerable degree of bacteriological contamination did the distribution system show relative recovery.

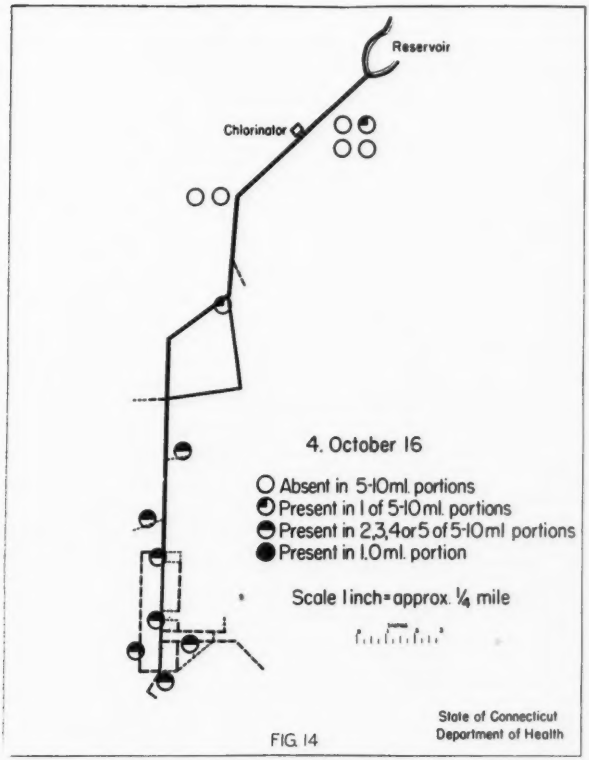
Reservoir
Chlorinator
4. October 16
Absent in 5-10ml. portions
Present in 1 of 5-10 ml. portions
Present in 2,3,4 or 5 of 5-10 ml portions
Present in 1.0 ml. portion
Scale 1 inch = approx. ¼ mile
State of Connecticut
Department of Health
FIG. 14

FIG. 14.—BACTERIOLOGICAL RESULTS OBTAINED DURING SECOND WEEK FOLLOWING BREAKDOWN OF CHLORINATOR.

One ordinarily thinks of water passing through the supply main and thence into various feeders and laterals, pushing the water ahead in the pipes along and out of the system through the consumer take-offs, more or less like the passage of a train of cars along a railroad track. As a matter of fact, however, there is little likelihood of such action. What happens instead is that the water swirls through the pipes setting up transverse and reverse currents as it flows and impinges against the sides of the pipe. There is continuous mixing of old and new water, and questions of infection of pipe growths and

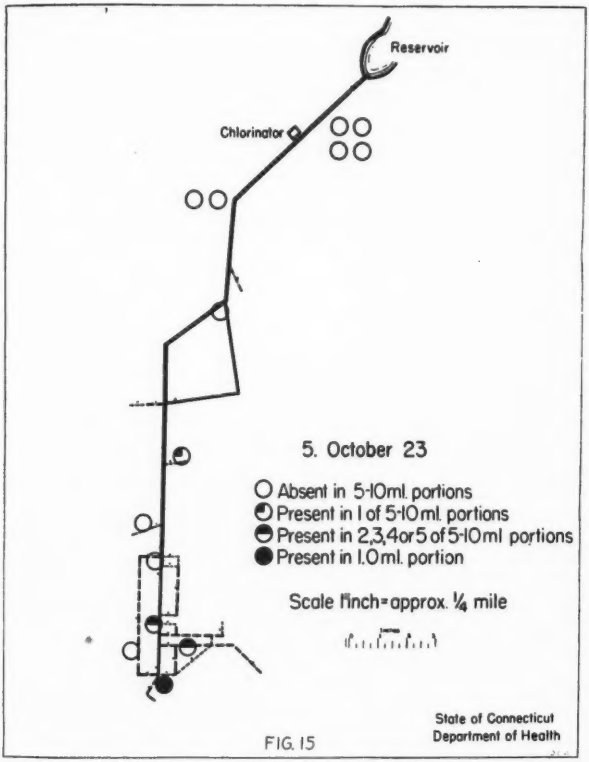

FIG. 15.—BACTERIOLOGICAL RESULTS OBTAINED DURING THIRD WEEK AFTER BREAKDOWN OF CHLORINATOR.

contact of the water with them enter into the picture. The after-effects of chlorinator breakdowns or even of short periods of inadequate chlorine dosage may be reflected in laboratory examinations of water in distribution systems for much longer periods than are ordinarily believed likely.

Discussion. At times when field indications are that water treatment is being carried out effectively, occasional samples from distribution systems will show up poorly by analysis, for reasons not apparent at first glance. Some explanations offered by Howard and

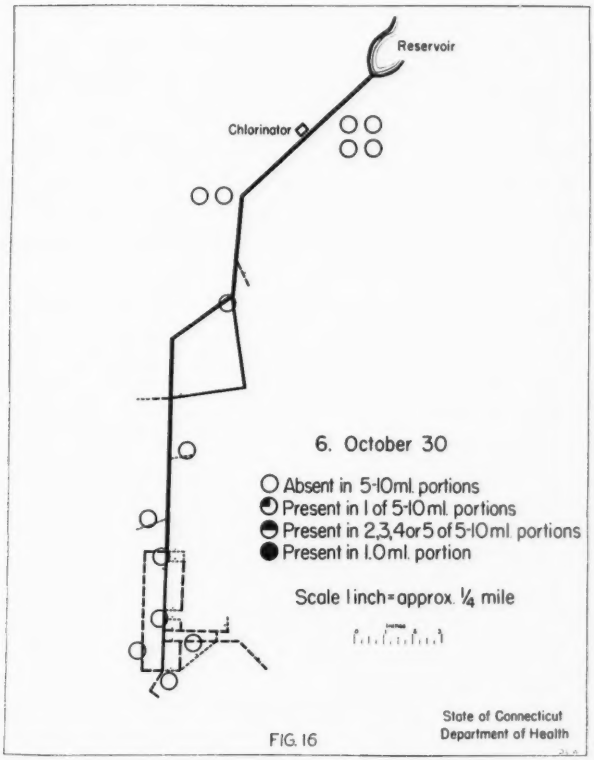

FIG. 16.—BACTERIOLOGICAL RESULTS OBTAINED DURING FOURTH WEEK AFTER BREAKDOWN OF CHLORINATOR.

others are that attenuated organisms under favorable water temperatures may start to multiply in the pipe system, that bacterial life present in a dormant condition on the sides of pipes may be released as a result of rising water temperatures, and that in the absence of sufficient residual chlorine natural decomposition of dead organisms may cause increased bacterial growths in the summer months.

This study of samples from three distribution systems, collected weekly over a period of a year, correlated with field observations of residual chlorine tests and other related data has indicated that tem-

porary interruption of chlorination or inadequacy of chlorine dosage may leave after-effects that will result in poor samples being drawn from distribution systems for many days or weeks. Very rapid changes in the chlorine demands of unfiltered surface waters were noted even in a period of a few hours, testifying to the likelihood of frequent inadequate chlorination.

The discrepancy in comparative studies between strict adherence to "Standard Methods of Water Analysis" and a modified method of bacteriological analysis was not great but it was decided to adhere to "Standard Methods" closely in the future.

Conclusions. Certain conclusions and desirable objectives suggest themselves as a result of the study:

1. Ortho-tolidin control of chlorine dosage by periodic manual tests, is unquestionably ineffective at times, especially for unfiltered surface waters, due to rapid change in the chlorine demand. The development and use of automatic control by photo-electric cells or other methods would be a great safeguard.

2. Water supplies should be systematically sampled throughout the distribution systems so as to detect and follow up failures of treatment and to bolster the knowledge of distribution system conditions.

3. There should be more uniformity of laboratory procedures as to adherence to "Standard Methods of Water Analysis" so as to get comparable information. The number of laboratories with variations in vogue is unquestionably large.

4. It is the author's opinion that until more water laboratories adhere strictly to "Standard Methods" so as to build up more comparable analytical data and until better and more comprehensive analyses are made of distribution system sampling results, it is unwise to adopt more stringent bacteriological limits as part of the U. S. Treasury Department standard. These limits after all are based more on the ability of treatment plants handling polluted water to produce conformity than on any disease or experience data on the large number of chlorinated surface water supplies derived from clean watersheds. Coliform organisms to some extent will be found in distribution system samples of the most perfectly treated surface water supplied to date. Our standards must be based either on bacterial quality at the source or on arbitrary limits of the presence of coliform bacteria in the distribution system, and no words handed down in letters en-

graved on stone are available to set these limits definitely. It is absurd to pick figures out of the air and condemn a large number of supplies including those of many large cities where history gives no evidence of danger. Reason should prevail in setting standards and not arbitrary opinions, even though these opinions are softened by what may be really a gentle impeachment, that all results should be interpreted in the light of conditions.

5. The experience of the Connecticut survey brings once again to mind that bacterial infection of a distribution system may occur in a relatively short number of hours or even minutes, due to a temporary lapse in treatment. This lapse may not be disclosed by examination of routine samples at the point of treatment. At the same time, it should be borne in mind that even in the face of apparently adequate treatment, analyses of samples from distribution systems occasionally give puzzling laboratory results. This is why more attention to analysis of distribution system samples will furnish much basic information on which to consider interpretation of laboratory findings. Poor distribution system samples may not always be due to dirty sampling taps or to cross-connections. It is unfortunate that extensive programs of examination of distribution system samples place a heavy load on water laboratories, but in the author's estimation efforts toward promoting such programs will produce more knowledge and do more good than changes in bacteriological standards of quality at this time.

6. For small unfiltered surface supplies and even for large supplies of similar type, super-chlorination followed by de-chlorination may be the ultimate answer to unsatisfactory disinfection that is occasionally obtained. This would permit wider margins of chlorine dosage above the chlorine demand without making the water unpalatable. Ammoniation in conjunction with chlorination will give a leveling off of poor distribution system samples although where water takers are situated close to the point of treatment the slower disinfecting action of chloramines must be considered. Recent investigations indicate that where ammonia is present in water, better disinfection and improved taste and odor conditions may be obtained by raising the chlorine dosage beyond the so-called break point. This may lead to increased use of ammonia combined with higher chlorine dosages. Filtration of all surface water supplies, even from clean

watersheds, is being instituted increasingly to improve physical characteristics of water and incidentally will lessen the peaks of chlorine demand and add to chlorination efficiency.

DISCUSSION

GEORGE NORCOM.* I should like to take this opportunity to compliment Mr. Scott on the results of his investigation. I am especially impressed by the common sense of his conclusions. He has said a lot of things that one does not often find in textbooks, particularly regarding the application of the Treasury Department standards to water samples taken from distribution systems. I believe he has indicated clearly one trouble that is liable to be encountered in any supply that is subjected to chlorination alone, even if it be automatic chlorination. I believe that if the installations referred to by Mr. Scott had been manual chlorinators, conditions probably would have been worse. We have a protective weapon in automatic chlorination that is really of great value. Nevertheless, as this study so clearly shows and so well confirms operating practice on straight chlorination plants, there will be times, even though the occasion may be inexplicable, when in spite of a clear record at the point of chlorination the distribution system will begin to show positive results for coliform organisms. This happens in spite of the fact that chlorination has been either automatic or very carefully controlled. Once this condition is established in the distribution system positive coliforms may persist for months, in spite of every effort that can be made to clear the mains either by flushing or by increased chlorine dosage, or by the use of ammonia at the point of application in the hope that enough residual can be driven into the mains to somehow reach the organisms. This is very embarrassing and will give rise to a period in the record when the water will not pass the Treasury Standards. Under these conditions, there is room for some latitude as to just how the Treasury Standards should be applied. Should it be inferred that the water drawn from one portion of the distribution system is unfit to drink because samples drawn from it are still positive when perhaps 98% of the distribution system has already cleared up? I agree with Mr. Scott that there must be considerable caution and plenty of thought

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before tightening up on standards, particularly where there is no evidence of outbreaks of intestinal disorders from the areas in which the positive results are occurring.

CHARLES R. COX.* Studies such as those by Mr. Scott and his associates are greatly needed to clarify the control of the quality of water passing through distribution systems.

A recent survey of the laboratory control of public water supplies, by the Committee on Water Supply of the American Public Health Association, has disclosed a remarkably inadequate program of sampling of most supplies, including many serving large municipalities. One salient disclosure was that comprehensive collection of samples from representative faucets on distribution systems has not generally been arranged for, so that the actual quality of the water reaching the public is not known in many instances. As a particularly bad instance, it was reported to the Committee that a city of over 300,000 population served with a chlorinated supply did not maintain any laboratory control and that the only knowledge as to the quality of the water reaching the public was furnished by the independent examination of samples of water by the municipal health department. In general, therefore, more extensive sampling should be provided.

Public health departments fundamentally are interested in the quality of the water reaching the public. There are indications, therefore, that the proposed revision of the Treasury Department Standards of water quality is to embody a requirement that samples used in appraising public supplies serving interstate carriers be collected directly from distribution systems. This situation, while justified, imposes a practical administrative problem because of the discrepancy between the apparent quality of the effluent of treatment plants and the quality of the water that reaches the public. In other words, there is a practical need for some procedure of evaluating the sanitary significance of secondary pollution.

It would seem that the correlation between bacterial pollution and high water temperatures may furnish an important clue to the solution of this problem. For instance, it would be very unlikely for inter-connections and cross-connections to be an important pollution factor *only* during seasons of high water temperature. In the absence

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of open equalizing reservoirs, standpipes, or elevated tanks, whereby secondary pollution by dust, birds, etc., might occur, one would conclude that the data discussed by Mr. Scott indicate that a biological factor is involved.

The question of so-called after-growths received considerable attention in years past. Apparently most bacteriologists concluded that a significant growth of coliform organisms did not occur in distribution systems. In fact, storage of water has been held to lead to the gradual diminution of the number of such organisms. The subsequent disclosure that coliform organisms will thrive on jute and other packing materials, the known complexity of the coliform group and the growing realization that little is known about the biology of pipe growths indicate that this subject needs reappraisal and more extensive study. It seems desirable that such a study should include an investigation whether barely adequate doses of chlorine merely "stun" organisms and prevent their development in culture media that are inoculated with samples of freshly chlorinated water, and if so whether those organisms that survive the action of chlorine are able to develop in culture media that are inoculated with samples collected from the distribution system at points where residual chlorine no longer persists.

Another problem needing further study is whether barely adequate chlorination that produces an apparent average coli index somewhat less than the standard of 1.05 per 100 ml. when samples of freshly chlorinated water are examined, is followed in the same water, after relatively quiescent passage through a distribution system, by changes in bacterial density as a result of sedimentation, so that many samples are better than the average and other samples contain appreciable concentrations of coliform organisms. A catch sample collected at a time when high-velocity flow, following a period of relative quiescence, picks up previously settled coliform organisms into the flowing water would then present a high coli index.

Another important problem is to determine more accurately the bactericidal action that occurs at minimum concentrations of residual chlorine. It will be recalled that Mr. Scott's data disclosed that bacterial pollution occurred at warm water temperatures that were accompanied by relatively high chlorine demands of the water. The evidence indicates that the chlorine dose was increased with an increase in chlorine demand so that the usual concentration of residual

chlorine prevailed. One is not certain, however, that the residual chlorine in water with a low chlorine demand does not have higher germicidal value than the same apparent concentration of residual chlorine in water having a higher organic content. In fact, studies now in progress in the laboratory of the New York State Department of Health indicate that the reactions between chlorine and organic matter may lead to reaction products that give positive color changes with orthotolidin and yet represent substances of low germicidal power as contrasted with the germicidal power of hypochlorous acid formed in chlorinated water of low organic content. It has been found that, pending further information, the *relative* values indicated by orthotolidin, flavone (alpha-naphtho flavone) and neutral starch iodide reagents are of considerable help in estimating the *rate of disinfection*. The so-called "flash" test with orthotolidin is simple and gives information as to the presence of "active" chlorine as contrasted with chloramines, etc. The immediate appearance of 80% to 90% of that color recorded after 5 minutes indicates the presence of hypochlorous acid or "active" chlorine.

In other words, the whole field of chlorination needs reappraisal in terms of oxidation potential, the nature of chlorine reaction products, the specific resistance of organisms of the coliform group, and the biology of "pipe growths".

NORMAN J. HOWARD.* I would like to say that we have had experience with superchlorination over a period of possibly 15 years, and that this form of treatment will not prevent these growths. I say that very definitely. After-growths occur in our distribution system following superchlorination of the filtered water. Similar growths have been extensively reported in many large American cities during warm-water periods. The only disquieting feature is that the positive tests invariably parallel periods of raw-water pollution and it is during these periods that superchlorination is employed. As the water enters the distribution system it is practically sterile, but at remote parts of the system some secondary growths occur. The normal dose of chlorine which approximates 0.35 p.p.m. is raised to 2.5 p.p.m. yet these growths are still reported.

There is one condition, which we noticed this summer, that is

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rather unusual but significant. A water temperature of 67° F. existed at the time, and after growths were present. Within 24 hours the temperature dropped to 47° F., due to change in wind direction, and immediately most tests were reported negative. With a rise in temperature within 48 hours up to 60° F., positive tests again occurred. There is definite evidence that the temperature factor largely controls this situation. I do not believe, speaking generally, that these positives occur without a rising water temperature, neither do I think that they are of sanitary importance. I do not believe that there is any question but that after-growths are due to a changing flora within the distribution system. In some manner, probably due to temperature changes, the slimy coating of the pipes becomes detached and the bacteria are absorbed by the water in the distribution system.

There was one other matter that occurred to me in connection with Mr. Scott's paper. I was wondering what was the basis of his deduction that short circuiting occurred in the distribution system. Our experience has been very clean cut in studying conditions following short waves of taste within the distribution system. Occasionally we have had a chemical taste in the water that has occurred before corrective treatment had been applied. In investigating the areas involved in taste, we found that the offending water appeared to pass in mass formation through the distribution system. A chart could be prepared showing the progressive passage of the water through the mains. In some instances it was reported several hours later at remote parts of the distribution system.

MR. SCOTT. In reply to Mr. Howard, I would say that I emphasized that there was little likelihood of rapid *complete* displacement of water in a distribution system. The center velocity in a pipe is greater than the side velocity and there are considerable changes in velocity of water as it flows through bends in pipes, all of which tends to cause swirling action and set up currents and back currents. The gridironing of water distribution systems also affects the spread of water displacement. The question of contact with pipe growths enters into the picture. Mr. Howard mentioned that, from taste observations, he considered that the water in a distribution system is displaced pretty rapidly. I believe, however, that while taste observations may indicate rapid displacement of *most* of the water as would be expected, taste

is a rather crude index of *complete* displacement. Our detailed studies have appeared to show a somewhat gradual movement of bacterial contamination through and out of the system, certainly much less rapid than would be expected at first hand.

With regard to super-chlorination, this would definitely tend to offset the effect of rapid changes in chlorine demand on unfiltered surface waters. It may not be a complete answer, however, to the problem of poor bacteriological samples in distribution systems.

THOMAS M. RIDDICK.* A good deal of the chlorine-ammonia treatment reported to date has been arbitrary, using fixed ratios of 1:3, 1:4 etc., and little consideration has been given to the organic demand of the water or to the point of application of chlorine and ammonia. This has resulted in non-uniform results, and at times in poor sterilization.

The ratio of chlorine to ammonia should be used on the *available* rather than total chlorine dosage. Take for example, a plant treating water from a flowing stream and applying chlorine and ammonia befor filtration. In winter, the chlorine dosage will be, say, 0.70 p.p.m. and ammonia dosage (1:3 ratio) 0.23 p.p.m. The organic chlorine demand will be low, about 0.3 p.p.m. which leaves 0.4 p.p.m. (0.7 less 0.3) as *available* chlorine. The true ratio of ammonia to chlorine is therefore 0.23:0.40 or 1:1.7.

Now consider operation at the same plant during the summer months when vegetation is rank in the stream. To maintain the same residual as before, the chlorine dosage must be increased to say 2.5 p.p.m. If the same ammonia chlorine ratio of 1:3 is maintained, the ammonia dosage will be 0.83 p.p.m. However, the organic demand of the water will now be high—say 2.1 p.p.m., leaving 0.4 p.p.m. of available chlorine. The true ratio of chlorine to ammonia is changed to 0.83:0.40 or 1:0.5—or the amount of ammonia is far greater than the amount of chlorine, which is undesirable.

This example is not greatly exaggerated, though it is realized that *available* chlorine is a relative term and is not exactly equal to chlorine dosage less organic demand. The fundamental contention, which seems to be substantiated by plant operation, is that chlorine has a greater affinity for organic matter than for ammonia.

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I believe that the original contention that chloramine is much slower acting than chlorine, is erroneous in its practical aspects, since ammonia permits the maintenance of high residuals, and a chloramine residual of 0.45 p.p.m. will sterilize as effectively and as quickly as a chlorine residual of 0.30 to .35 p.p.m. The practical solution of the problem is to apply sufficient primary chlorine to the raw water to satisfy the organic demand and to add ammonia and chlorine to the filtered water only. With this arrangement, constant ratios of ammonia to chlorine of 1:2, 1:1.5 or 1:1 may be successfully employed and will result in maximum sterilization and maintenance of residual.

In regard to the length of time that a chlorine residual will hold up in a distribution system, this may depend upon the extent of the period during which chlorine-ammonia has been used. From two to four months are required to oxidize organic matter in old pipe lines, but after this, a residual of about 0.2 p.p.m. should be obtained in any part of the system when a residual of about 0.4 p.p.m. is maintained in the plant effluent.

I believe that the above points have bearing on Mr. Scott's splendid paper and possibly explain some of the differences in bacteriological quality following contamination of the supply.

WATER SUPPLY IN TIME OF WAR

BY F. F. LONGLEY*

DISCUSSION BY THOMAS H. WIGGIN†

When Colonel Longley took charge of the 26th Engineers, A.E.F., he was of just the right age so that many of his former associates at West Point were in staff positions. That included the general staff and also the staff of the lines of communications, and this personal acquaintance made for quick understanding and quick action on water supply needs. The writer, as officer-in-charge of water supply and sewerage in the lines of communication, was at all times in close coöperation with Colonel Longley and speaks from intimate knowledge.

Colonel Longley's contribution in getting the Medical Corps to agree to relinquish its primary control of the quality of water supply and to put it in the hands of the Corps of Engineer was a master stroke. Attainment of this was aided by Colonel Longley's standing in the army as a graduate of West Point, by his reputation as a water supply engineer in civil practice, and especially by the broad-minded character of General Ireland, Chief Surgeon, A.E.F., and his early recognition of the logic of centering all water supply activities, quality control as well as production, in a single, competent organization. Historically, the control of the quality of water supplies had been a responsibility of the Medical Corps, and it started out in that way in the A.E.F.

When we began to investigate water supplies over the lines of communication, we relied at first on the medical laboratories, and the results were very peculiar from a water supply standpoint. For example, the writer saw a medical lieutenant come out with a couple of water sample bottles for bacteriological analysis stuffed into his trousers pocket, stopper down. Samples were taken without the degree of care necessary for water, though doubtless all right for pathological work where bacteria are numerous. The early results always showed that the water was full of *B. coli*. The laboratory reports

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showed *B. coli* even in the water from the Lyster bags, a situation that the writer does not understand to this day.

The way water in Lyster bags was sterilized was as follows: The Lyster bag contains about a barrel of water and has several spigots. It is hung up in a company street so that all the soldiers can fill their cups or canteens from it. The treatment of the water consists, or did in those times, of putting in the contents of a little glass tube containing chloride of lime. Every morning, the first sergeant, or whoever had charge of the Lyster bag, would drop the contents of one of those tubes of chloride of lime into the Lyster bag, and during the day maybe only a third of the water in the bag would be drawn. On the next morning, the bag would be filled again without emptying and another dose put in. At the end of about two weeks that water was very suggestive of Dakin solution. But even such water had *B. coli,* in it in accordance with some of the analyses.

After G.O. No. 131 was issued control of quality of water supplies passed into the hands of the Engineers under the arrangements with the Medical Department described below.

Previous to that time several water laboratories had been established, and, by arrangements suggested by Colonel Longley and furthered by myself as water supply officer of the lines of communication, a man whom many of you know, Colonel Edward Bartow, was put in technical charge of the laboratory personnel and the laboratories, and not only the laboratories in the lines of communication, of which there were something like seven, including one in England, but also the laboratory work in the Army, which was of course a mobile matter. Those laboratories were manned by men obtained from the Sanitary Corps of the Medical Department in large measure, and so close were the relations between Colonel Longley and the Sanitary Corps of the Medical Department that it was possible at any time to get any Sanitary Corps officer who had the required qualifications and experience transferred to the Water Supply Service under Engineer command for service in the water laboratories. In that way, quite early in the war, we had some fairly well-equipped laboratories and were getting the same kind of service back of the lines that is obtained by the board of health service here. I think it was exceedingly well done.

As Colonel Longley has covered his subject so well, and has

had such splendid assistance from Major Pratt, I am just going to say a few things, somewhat in reminiscence, to illustrate the kind of situations that arose and had to be met.

The supplies were always a question. In the early stages of the war, there had been made up in Washington by a force, with which Colonel Longley had much to do, a list of water supply material. This material was sent to France quite early and was very helpful. It contained a lot of Universal pipe which the soldiers quickly learned to lay. It also contained a lot of wood-stave pipe that had evidently been made under wartime conditions and invariably did not seem to hold water very well. That is no reflection on well-made wood-stave pipe, which the speaker has seen used very satisfactorily, but this pipe appeared to have been made of unseasoned stock by amateurs. Doubtless many skillful coopers of wood pipe had been drafted to war.

Infantry soldiers laying Universal pipe had a tendency to think that if a 1-ft. wrench was good a 2-ft. wrench would be better, so that they started in to pull the lugs off. Fortunately in the early stages, one of the field engineers of the Universal Company came to the speaker's organization. He was asked to draw up a sheet of instructions. These were blueprinted and he was then sent around to show people how to lay the pipe and to leave copies of the directions. Afterwards we had no difficulty with this pipe.

Early in the war, we purchased in England about 200 miles of 4-in. cast-iron bell-and-spigot pipe with all fittings listed to go with it. This pipe was very useful but unfortunately the idea of the 4-in. pipe got so firmly fixed in the mind of a certain officer involved in the problem of water supply materials, that when he was transferred to Washington a few months later to instruct them in the needs of the A.E.F. he let it be known in Washington that nothing but a 4-in. pipe was necessary for Army purposes. This idea was based in part on the English motto that an army division advanced astride a 4-in. water main. Immediately all of our purchase orders in the United States for larger pipe were cancelled. Thereafter most or perhaps all of the larger pipe was obtained in Europe.

There was another idea that looked very nice from the headquarters standpoint but worked out very badly for army water supply. That idea was competition in unloading vessels. It probably origi-

nated in general headquarters, and there was a prize flag that was awarded monthly to the port that was most efficient in unloading vessels. U-boats were very active, tonnage was deficient and time lost at ports was important. The vessels were coming in at Bordeaux, Bassens, St. Nazaire, Brest, LeHavre, La Pallice and other ports. Each port was rated in accordance with its estimated standard capacity, and the tonnage unloaded was rated on a percentage basis, above or below what the port was rated as being able to do. The unloading went pretty fast but with the result that such things as wooden tanks, for example, that came over in bundles, each numbered, were distributed along the wharf, and when one ship was unloaded the contents of another ship were in part unloaded on top of the first cargo, and so on. It took something like six months to get the first tank together. We never got many of the others together, and finally had to get the missing parts filled out by sawmills that were manned by American troops.

As a matter of fact, there grew up a very large regiment called the forestry regiment, consisting finally of about 40,000 men, which had access to the French forests, some of which had not been used for some centuries and provided very good timber. This regiment had American sawmills and shaping tools, and after a while we got them to manufacturing tanks. After that there was less interest in finding the missing pieces of tanks shipped from America.

The same thing occurred with the railroad locomotive water supply columns. Those were very badly needed because the United States Army had increased the transportation facilities all over France, and a lot more columns were needed to supply the locomotives. Those columns were spread around in such a way that it took months to get them together due to this same unloading.

At about that time we had ordered in England several miles of 12-in. pipe. It came in at Le Havre and was unloaded by the hurry-up boys. They dumped it in a pile, a good deal as you may have seen pulpwood piled at a paper mill. The result was 45% breakage. Some of the pipe was ruined beyond the possibility of use.

There was one thing that was a lifesaver in the matter of getting water supply work done. That was the establishment of a depot where the supplies were arranged systematically, counted and listed, so that it was known what was on hand, and the material was

issued in some orderly way. That very desirable matter was accomplished by the coöperation of Colonel Longley and his regiment, the 26th Engineers. A platoon of that regiment was sent down to the big storage depot at Gievres and took charge of the water supply material as it came in on trains. If it had not been for that system, we could never have got any water supply construction job done except with such material as we could have picked up in France. The water supply section of that big depot became the nucleus of a system that spread over that whole depot for other supplies as well.

The French supplied us with a lot of pipe, particularly the larger pipe, which we were able to get from a large foundry close to the front lines. It is surprising that that could be done because the foundry was within the range of bombing all the time, but somehow or other the foundry bore a charmed life, and the suspicion could not be avoided that influential Germans had stock in the company.

Another custom increased the difficulty of supplying hospitals of which a great many of large size were established by the American army. The choice of those sites was in the hands of the Medical Department, as it should have been in large measure. France has many beautiful chateaux, and each of them made an ideal spot for a hospital, so that the board of selection of a hospital site nearly always chose some existing chateau as the central building. The land around it became the site of the various barracks for the hospital units. The hospital units were of about a thousand beds each, and some of those hospitals had as many as 25,000 beds. But most of these chateaux were on tops of hills, and perhaps five or more miles away from any possible water supply, so that it was necessary to have not 4-in. pipe but in some cases even 12-in. pipe in order to get a supply of water to the hospitals; the edict that pipe size should be limited to 4 in. was particularly unfortunate in those cases.

The quantity of water required by an army is a matter of a good deal of interest, and that was studied to a considerable extent, particularly for the lines of communication. For example, some of the camps got along with as low as 2 g.p.d. per capita. When lavatories and some water-flushed closets began to be installed, consumption crept up and reached 10 to 12 g.p.d. per capita. We tried to get 15 g.p.d. for hospitals, and sometimes consumption got up to 25 g.p.d. per capita. The corresponding limit here in America was

55 g.p.d. in camps, so that the hospital over there had less than half as much per capita in general as was allowed in this country.

Hand in hand with the water-supply problem went the sewerage problem. Sewerage systems are not very common in France, and the A.E.F. had in general to provide its own systems. Frequently these were wholly or mainly for sink wastes, other sewage being provided for by latrines or soakage pits. The French are not accustomed to putting much of their pollution into their streams, and they did not wish the A.E.F. to do so. We asked them what type of sewage purification plant they wanted. They replied, "We will show you some good sewerage plants." So Colonel Bartow and the writer inspected a sewage purification plant offered as the example, but found it without practical effect as regards purification. Other examples were promised but finally the French threw up their hands and said, "Anything that suits you, suits us; you probably know more about the sewage business than we do." We adopted for sink wastes plain sedimentation with periodic removal of sludge as the only method practicable for war-time plants. One or two crude Imhoff tanks were built for combined human and sink wastes, but most human wastes were cared for by burial and soakage pits.

American soldiers like to short cut: they do not like the trouble of sorting out and carrying off garbage if this labor can be avoided. What they did was to puncture the sink strainers with bayonets and flush everything down that would go. It was surprising what a tremendous volume of coffee grounds would come from even a small number of soldiers. The writer saw one good sized sedimentation basin about 90% filled mostly by coffee grounds. The only way in which that kind of sewage could be disposed of was to shovel it out and start over again, repair the sink strainers and hope they would last, which they never did.

The writer wishes to mention a few thoughts on the difference between the war as he knew it then—which really was a relatively kindly affair for the A.E.F. which, until the last few months, stayed behind the French and English lines—and the present war. The writer has not seen any reports of what has been happening to the English water supplies in all this bombing. London, for example, is supplied to a considerable extent through a number of large reservoirs which would be very vulnerable to attack. It seems incredible

that some of the embankments should not have been breached, but there has been no account of it.

The French supplies are not so much in evidence as the ground is generally limestone and is full of caves and crevices, so that ground water is very common. For example, we put down two wells, one near Bordeaux and one at Bassens not far away. At a depth of 1100 ft. Artesian flow was obtained, the flow in one well being about 400 g.p.m. and in the other 350 g.p.m., rising about 40 ft. above the surface of the ground at point of shut off. Tight rectangular tanks were put around these wells so that they did not flow when the water was not being used. The suctions of pumps were attached to the tanks and, by adding a little chlorine, an excellent supply was obtained for the American forces in those two ports.

In many other places, large springs were used. As an example of French supplies the large city of Bordeaux is entirely fed by many springs with masonry coverings. Bombs would probably not hit many of these springs in a long time, according to the laws of chance.

But if the much-heralded new American bombing sight were in use, which is reputed to enable an aviator perhaps 15,000 ft. in the air to hit inside a 10-ft. circle, then it would be possible to hit our water supply structures. Hence the writer believes that there should be an active investigation of what is required to protect our large dams and gate houses.

For example, what would be the effect of a high explosive shell hitting close to the water face of Kensico Dam, where there are about thirty billion gallons of water in storage about 25 miles north of New York City? A large breach in this dam would carry a tremendous river right down through the Bronx Valley, probably drowning a large number of people. The flood would probably go right across the Harlem River and into New York City.

At the time of the last war, the writer discussed this subject with persons skilled in handling explosives. They were doubtful if much damage would be done by a single explosion as the dam was thought to be too massive. The writer is inclined to think that they are right, but believes that we ought to know beyond doubt. He thinks we should know what it takes to protect those dams, and if it is necessary to put heavy rafts or other protection back of each of them to prevent the concussion traveling to the dam, or if it is

necessary to put armor plate over the tops of them, we should be prepared to do it, and similarly with our important gate houses. When we are spending ten or fifteen billion dollars on defense, the building of a dam for experimental purposes would be a mere bagatelle.

The writer has seen descriptions of craters 36 ft. in diameter by 18 ft. deep formed by modern air bombs. One such hole in the top of an earth dam might release the water and a "stick" of such bombs well placed would almost certainly do so.

The matter of protecting dams should be investigated. There is a very bad gap in our information as to what would be needed to protect dams and gate houses. Maybe the army experts on explosives know all about it. Of course there are other explosive experts who could tell us something about it. But the writer thinks that we ought to know something about such protection, and if this Association has no committee charged with it, perhaps this problem should be annexed to the duties of some committee on water supplies in war time.

Restriction in the use of water in case of partial destruction of a supply is of course possible. New York City for example gets 10 or 15% of its water from many widely distributed wells, and it would seem impossible to destroy all of them by bombing. If necessary, the civilian population could get down to a very small per capita consumption if the larger supplies were damaged.

It seems to the writer that investigations with regard to what might be done in minimizing the effects of damage by cross-connecting supplies and other means has been outlined admirably but that we have not yet really faced the problem of how to protect our major structures.

One statement by Major Pratt reminded the speaker of an experience. He said, and rightly, that the organization of special troops of water supply is not entirely recognized by the army. The writer recalls that after the armistice, when the troops started to march into Germany, there was a general gathering up of all kinds of special troops for return to America. There seemed to be undue haste in that, apparently due to a feeling against the principle of having specialized troops. Use of all of the steri-labs, i.e. filter and chlorinating plants on trucks, appears to have been discontinued and such equipment sent to army dumps. The writer was still in Tours at

headquarters of the lines of communication carrying on in connection with providing camp facilities for the evacuation of the troops to America. Then he began to get telephone messages from the front as to where the steri-labs were. The outcome was that we intercepted several of the special troops that came through Tours and made up three or four crews of steri-labs and told them at which dumps to find the steri-labs. The officer in charge of the water laboratory at Tours, Captain W. F. Wells, had taken pains to find out where these equipments were left from officers who came through Tours on their way home. Thus those steri-labs were remanned and went back to places that they never should have been allowed to leave. Some went with the A.E.F. troops into Germany. This experience bears on the problem whether special army water supply troops should be provided or the attempt made to have regular engineering troops trained for all kinds of service.

Another experience may be of interest. We built a dam at one of the important French seaports, and it is still there and they are still using it. The writer saw it again in 1934. The A.E.F. needed the dam in a hurry. It was an earth dam, and the engineer colonel in charge at that base selected a lieutenant to build it. The writer went out shortly afterwards to find out how he was doing it. The lieutenant greeted him in this wise: "I seem to be the only speed merchant around here so that they told me to build this dam in a hurry, and I am doing it." He was starting at the banks and back-dumping without any ramming or rolling whatsoever.

The dam was going to be about 35 ft. high, an earth dam, and the writer was not sure at all that it was going to hold any water when it was completed. With the coöperation of the base engineer the writer arranged for one of his water supply engineers with experience on dam construction to be assigned as inspector. Back-dumping was stopped, much of the back-dumped material was spread and rolled as well as could be done without too much re-handling, and the rest of the fill placed above. The dam leaked only slightly and the same leaks were there 17 years later in 1934.

It takes experienced personnel for water supply in an army as for water supply elsewhere. The organization that was made up in the A.E.F. was a good one, and the writer believes that in another war a similar one would work. There is no proof that the same

success could be attained without special troops and personnel, though it is conceivable that such personnel could be attached to divisional engineering troops under some functional supervision of water supply engineering and laboratory specialists attached to headquarters.

Discussion by F. W. Scheidenhelm*

I am sure that in his felicitously flattering introduction, Colonel Longley did not have in mind that I should thrust back at him, but the fact is that I believe that, out of all of the personnel available to the United States Army in 1917, there could not have been selected a man better adapted, by reason of natural ability, training, personality and acquaintance, than he to accomplish what was necessary with regard to the water supply for the American Expeditionary Force in France. I refer both to the water supply for the fighting troops and to that for the Services of Supply in the rear areas, the S.O.S. His peculiarly appropriate qualifications have been touched upon by various of the speakers and I shall not attempt to go into further detail upon them, except to add that it was most fortunate that there was available a man who as an engineer in civil life had had extensive and thorough experience in the field of water supply but who also was a graduate of West Point, familiar with the methods of the Army, acquainted with many staff officers and with practically all of the commanders of the engineer regiments where they were regular army officers, and able to get along with the personnel associated with him.

It happens that my own experience in military water supply during the First World War was in the last of the three categories treated in the author's paper, that is, in the combatant zone, first, as a staff officer at G.H.Q. under Colonel Longley, later as Water Supply Officer on the engineer staff of First Army, A.E.F., and finally in the combined rôle of Water Supply Officer, First Army, and Commanding Officer of the 26th Engineers. As time went on, under the standard military procedure those of us who had to do with water supply at the front nominally became separated from Colonel Longley; we were no longer under his command. If he desired that an order be trans-

*Consulting Engineer, New York, N. Y.

mitted formally, it was necessary that it pass through military channels, including the Chief Engineer, A.E.F., and the appropriate section of the General Staff at G.H.Q., up to the Commander-in-Chief, General Pershing, and then down the line to the staff of First Army or Second Army, as the case might be. (Incidentally during the early part of the American campaigns, General Pershing acted in the dual capacity of Commander-in-Chief, A.E.F., and Commanding General, First Army.)

As a practical matter, however, the long way around was used only with regard to matters of policy and confirmations, whereas the routine contact was across the line or, so to speak, through a hole in the fence. Colonel Longley and those serving with him were of tremendous help in enabling those of us who had to carry on the work at the front to obtain what we needed by way of advice and otherwise. Matériel constituted the crying need. For instance, for the St. Mihiel offensive, which began September 12, 1918, instead of water-tank truck-trains we had to resort to make-shift transportation of water, by putting huge French wine casks on ordinary army trucks.

As regards matériel, most of the personnel of the Water Supply Service at the front may not have realized, as fully as did Major Pratt and I, how important a part was played by those in the S.O.S. and by Colonel Longley and his staff, including Major (later Lieut. Colonel) Leonard P. Wood, a member of this Association. Time and again, usually late at night, I have struggled with and over the woefully inadequate telephone lines (Army field-lines, French local lines and then American and French long-distance lines) in order to get some word back to the S.O.S. that we needed this or that. What a relief it was if, as usually was the case, I was able to get Major Wood on the line! Then he would get busy and somehow the matériel, if it was available in France, would get up to the front.

The author has pointed out clearly the distinction between what we may call the retail and the wholesale aspects of supplying water for large bodies of troops under combat conditions. As to the former aspect, the responsibility in respect of local transportation of water and even the quality thereof lies with the troops which are to be served, e.g., with the infantry company or the artillery battery. As to the wholesale aspect, on the other hand, the responsibility lies in general with the engineer troops regularly forming part of the division

of combat troops or, if the needs be sufficient, with specialized engineer troops. For the warfare of position, such as occupied most of the time in the First World War, including the participation of American troops, the problem is likely to become one requiring special personnel, as it actually did in France. In general, the more nearly the warfare is one of fixed position on part of opposing land forces, the denser is the concentration of troops and the greater the problem of water supply in any given area.

A water supply sufficient in quantity for a field-army but located at a single point, even though it be the center of the area within which the army is operating, obviously is of itself inadequate. Indeed, for an army of the size of the American First Army in France, which at its maximum approximated 1,000,000 men, a dozen or a few dozen points of availability of water in wholesale would be inadequate.

To be sure, military water supply under combat conditions is necessarily somewhat crude. One does not have the facilities for a water supply which is fully adequate in quantity and acceptable in quality. Possibly it was that very fact, that the job to be done was a rather crude one, which made it possible for some of us in France to meet the needs of the case. Fortunately there was available personnel, especially officer personnel, which was experienced in the refined water supply of civilian life and made use of that knowledge and experience whenever conditions permitted and required.

But, in the main, water supply for a fighting army is not merely crude in its adaptation of available sources but subject to limitations quantitatively. Thus, along the fighting front in France, our aim was to supply an average of two gallons per man per day. Frequently, however, the supply was less, simply because it was impracticable to make more available. Bathing was a secondary or tertiary consideration, a luxury available in general only to troops in rest-areas, back of the fighting front. Even so, American troops required and were furnished with more water per man than the British and much more than the French.

In addition to the necessity of supplying water sufficient for the barest needs of the troops themselves, there was the problem of obtaining sufficient water for horses and mules. Of course that was a far greater problem in those days than in this day of mechanized warfare. For the animals, quality was of no substantial importance,

but frequently controlling conditions necessitated that such water as was made available be of a quality suitable for men as well as animals.

The importance of water supply to an army is evident when it comes to fixing priorities with regard to the use of roads, light (narrow gauge) railways and other means of transport. It is true that an army may be said to fight upon its stomach, but the fact remains that, as regards priorities, water was generally placed second only to ammunition. Indeed, at times the appropriate section of the staff of First Army would turn down priority demands for munitions and afford priority to water supply.

The importance of the problem as it presented itself along the front in France is manifested by the amount of personnel involved. Just before the American Second Army was split off from the First Army and the First Army was responsible for the front from the western side of the Argonne Forest southeastward to the Moselle River, the Water Supply Service of that Army involved a total of about 3,500 men and officers. This includes the 26th Engineers and various other troops, such as a company of the 37th Engineers (electrical and mechanical), a copy and part of another company of the 27th Engineers (mining) two Provisional Water-tank Truck-trains and five companies of the 59th Pioneer Infantry, the latter really furnishing labor.

As to methods and means, for various reasons the Water Supply Services of the First and Second Armies, A.E.F., followed more closely the practice of the British Expeditionary Force than that of the French Army. However, with the British, responsibility for the technical aspects of water supply rested with the Corps instead of the Army. Moreover, naturally enough, there came into being various differences in techniques, many of which were related to differences in terrain and in the local sources of supply.

The difference in requirements and viewpoints on part of the French Service des Eaux, the counterpart of our American Water Supply Service, find illustration in an occurrence during the preparations for the St. Mihiel "push". The First Army staff proposed to place a maximum of 600,000 men and 190,000 horses behind 22 miles of front line. Our Water Supply Service was called upon to furnish the necessary water for these troops and animals. The local French officer of the Service des Eaux, who had drilled more than 30 wells

in an unsuccessful effort to secure an abundance of pure water in this previously quiet sector, when told of the plans of the Americans exclaimed with characteristic French vehemence, *"Impossible! Impossible! Il n'y a pas suffisance d'eau."* But he had not reckoned on the use of surface waters to make a sufficient quantity available, and great was his astonishment when he first saw a water-purification truck in operation.

Much that relates to military water supply has changed, but to me it is not clear that there has been any change in fundamentals. Even that aspect—relative mobility of warfare—in which, superficially at least, there has been the greatest change, the change may not be permanent and almost certainly it will not be complete.

Mention has been made in this discussion of the possibility that, in case of mobile warfare, there would be difficulty in making contact with, let alone supplying water to, rapidly moving troops. Of course, in the case of American troops, that has not been tested under conditions of real warfare. However, in the latter part of the campaign in France we did have fairly mobile conditions—that is, for several weeks prior to the armistice. For "pushes" (such as the Argonne-Meuse offensive beginning on September 26, 1918, the battle orders had prescribed the places where the tactical units, infantry and artillery, could expect to find water by given times—all on the assumption that the ground would be gained as anticipated—and it was the duty of the water supply troops to fulfill what was stated categorically in the battle order. Most of the time the water was there, but I am afraid that now and then there was a slip. Sometimes the animals, generally mules, did not last—were shot, gassed, otherwise disabled or simply worn out, and men had to drag the wagons. As for getting a water-tank truck-train across No-man's land, that, in the first day or two of a "push", was generally not feasible.

As the Argonne-Meuse offensive grew more successful, the rate of forward progress of the American troops became accelerated and there was gradual transition from the procedure which I have just outlined. In the final days, detachment of the water supply troops of the First Army accompanied the rapidly advancing infantry and artillery, making the best, by repair where necessary, of water supply sources and facilities which were encountered. In large measure the officers in charge of those detachments were "on their own."

I am strongly sympathetic with the idea of making the divisional engineer unit, be it a regiment or a battalion, self-sufficient for all engineer functions. Anything short of that would not suffice for great rapidity of movement and of course would not suffice for a mechanized division. A divisional engineer unit cannot embody specialized personnel for each need which may arise, and very likely those needs cannot be met as well as if there were specialized personnel for each. But it seems to me that the necessities of the case dictate that under such circumstances the troops get along as best they can. If, however, we again get into a warfare of relatively fixed position or if our operations should extend into an arid region, such as parts of Mexico, then the problem of water supply will again come to the fore and specialized personnel will probably again be needed.

Indeed it seems to me that, if in 1940 there had not resulted that catastrophic defeat of the French armies, there would have eventuated at least temporarily, including the winter season, a warfare of position—call it a stalemate if you will—with correspondingly greater troop concentration in northern France than there had been behind the Maginot line. In such case there would again have come to the fore the problem of water supply which was so important in France in the First World War.

Let me now speak of a matter as to which the members of the 26th Engineers are greatly beholden to this Association. The older members may recall that following the First World War it became known that, whereas the members of the 26th Engineers had attempted to make provision financially for the publication of a history of the regiment and its work, yet funds in due course were lacking, partly because certain company funds had temporarily been practically confiscated under an ill-advised Army policy and partly because printing costs had sky-rocketed beyond the earlier estimates. That left a very difficult situation for those who in behalf of the already demobilized regiment were morally responsible for bringing about the publication of a regimental history. In this crisis there came forward the NEW ENGLAND WATER WORKS ASSOCIATION, at the instance of Colonel Longley and with the fine help of Charles W. Sherman of Metcalf & Eddy. The Executive Committee concluded to have the already-written history published as one of the issues of the JOURNAL.

With the aid of individual water supply engineers, arrangements

were made for financing the binding of that issue of the JOURNAL in a fine red and white cloth cover. Thus there appeared The History of the 26th Engineers as the members of the regiment received it. Incidentally, the white circle with superimposed red "W S", appearing on the back of the volume, was the symbol of the Army Water Supply Service in France. Undoubtedly many of you who were not directly concerned with water supply but were in the American First or Second Armies or even in the Third Army, that of Occupation in Germany, have seen that symbol at various places. It signified the presence of a water-point or of a detachment of troops having to do with Army water supply.

Now, in behalf of the members of the 26th Engineers, and very strongly in my own behalf, I desire again to express appreciation for what the NEW ENGLAND WATER WORKS ASSOCIATION did in connection with the publication of that history.

PROCEEDINGS

November 1940 Meeting

Hotel Statler, Boston, Mass.

Thursday, November 21, 1940.

President Leland G. Carlton in the chair.

Secretary Gifford announced the election to membership of the following: *Members*—Herbert Scott-Smith, Superintendent of Water Department, Waterbury, Conn.; Louis C. Campbell, Acting Superintendent of Water District, West Boylston, Mass.; Ernest Goobie, Superintendent of Water Department, Lynnfield Center, Mass.; and William A. Harris (with The Allpax Co., Inc.), Springfield, Mass. *Associate*—The Allpax Co., Inc., Mamaroneck, N. Y.

Harold A. Brigham reported upon the discussions at the Superintendents' Meeting and offered a resolution that a Committee be appointed to look into problems of sabotage. This resolution was carried.

A paper, "Notes on Operation of the Cambridge, Mass., Filtration Plant," was read by Fred E. Smith, Chemist, Cambridge Water Filtration Plant, Cambridge, Mass.

A paper, "Can My Town Afford a Water System," was read by Howard E. Bailey, Consulting Sanitary Engineer, Boston, Mass.

A paper, "Water Treatment at Groton, Conn.," prepared by A. N. Tiffany, Superintendent, Water and Electric Department, Groton, Conn., and Arthur L. Shaw, Consulting Engineer, Metcalf & Eddy, Boston, was read by John P. Wentworth. Thomas R. Camp, Guy Classon, and Fred E. Smith took part in the discussion.

December 1940 Meeting

Hotel Statler, Boston, Mass.

Thursday, December 19, 1940.

President Leland G. Carlton in the chair.

Secretary Gifford announced the election of the following mem-

bers: John B. Kennedy, Business Agent, Water Department, Winthrop, Mass.; Russell L. MacDonald, Superintendent, Holliston Water Co., Holliston, Mass.; Joseph Augustine McCarthy, Senior Chemist, Lawrence Experiment Station, Andover, Mass.; George Lawrence Winslow, Trustee, Water District, Auburn Me.; Peter Bolton, Commissioner and Treasurer, Water Supply District, Dracut, Mass.; Charles E. Burrill, Superintendent of Construction and Maintenance, Water Department, Winthrop, Mass.; Delwyn K. Barnes, Assistant Maintenance Engineer, Whitin Machine Works, Whitinsville, Mass.; Nicholas Ciaburri, Superintendent, Auburn Water Company, Auburn, Mass.

The President announced the composition of the Committee on Sabotage: Francis H. Kingsbury, Chairman, Howard H. Potter of Maine, Frederick O. A. Almquist, Jr., of Connecticut, Charles D. Howard of New Hampshire, Walter J. Shea of Rhode Island, and C. P. Moat of Vermont.

A paper, "Selective Service in the National Defense Program," was read by Major David W. Weden, Public Relations Officer, Massachusetts State Headquarters for Selective Service.

A paper, "Some Chemical Aspects of BREAK-POINT Chlorination," was read by A. E. Griffin, Assistant Director, Technical Service Division, Wallace & Tiernan Co., Inc., Newark, N. J.

A paper, "Manufacture and Laying of Large Precast Steel Cylinder Reinforced Concrete Pipe for the New Pressure Aqueduct of the Metropolitan Water District," was read by Stanley M. Dore, Assistant Chief Engineer, Metropolitan District Water Supply Commission, Boston. This paper was illustrated by moving pictures and stereopticon views.

January 1941 Meeting

Hotel Statler, Boston, Mass.

Thursday, January 16, 1941.

President Leland G. Carlton in the chair.

Secretary Gifford announced the election of the following members: Henry Banks Chandley, Superintendent and Assistant Manager, Beaver Falls Municipal Authority, Beaver Falls, Pa.; Edwin Carl Goehring, Chemist, Beaver Falls Municipal Authority, Beaver Falls,

Pa.; Hugh J. Loughlin, Engineering Inspector, City of Waterbury, Waterbury, Conn.

A paper, "The Development of Stoughton's New Water Collecting System," was read by Laban C. Morrill, Engineer, Stoughton, Mass.

A paper, "The Economy of Diesel Power for Pumping," was read by Joel W. Reynolds, Gustavo-Preston Company, Superior Diesel Engines, Boston.

A paper, "Advantages of Purchased Power," was read by Wellen H. Colburn, Engineer, Boston Edison Company, Boston.

Messrs. Roger W. Esty, Percy R. Sanders, and Francis H. Kingsbury took part in the discussion.

ASA
A21.1-1939

American Recommended Practice

MANUAL FOR THE COMPUTATION OF STRENGTH AND THICKNESS OF CAST IRON PIPE

With Historical Foreword on Specifications Relating to Cast Iron Pipe and Fittings

Approved by
American Standards Association
December, 1939

SPONSORS

American Gas Association
American Society for Testing Materials
American Water Works Association
New England Water Works Association

Approved by New England Water Works Association September 12, 1939

FOREWORD

On September 10, 1902, the New England Water Works Association adopted Standard Specifications for Cast Iron Pipe and Special Castings. These covered bell and spigot pipe and fittings and contained ten classes, A to K. The allowable heads for these classes were not given in the specifications but the thicknesses were based on allowable heads varying by 50 feet; 50-ft. head for Class A, 100-ft. head for Class B, up to 500-ft. head for Class K. Fairly complete dimensions were given, also weights of pipe and fittings.

In 1904 the American Society for Testing Materials adopted Standard Specifications for Cast Iron Pipe and Special Castings. These covered bell and spigot pipe and fittings and contained four classes, A to D, with allowable working heads varying by 100-ft.; 100-ft. head for Class A to 400-ft. head for Class D. Dimensions and weights of pipe were given.

On May 12, 1908, the American Water Works Association adopted Standard Specifications for Cast Iron Pipe and Special Castings. These covered bell and spigot pipe and fittings and contained eight classes, A to H, with allowable working heads varying by 100 feet; 100-ft. head for Class A to 800-ft. head for Class H. Fairly complete dimensions were given, also weights of pipe and fittings. Classes A to D were the same in thickness as in the A.S.T.M. Specifications.

The Sectional Committee (A21) on Specifications for Cast Iron Pipe and Special Castings, which developed the specifications contained herein, was organized in 1926 under the rules of the American Engineering Standards Committee, now the American Standards Association. The sponsor societies are the American Gas Association, the American Society for Testing Materials, the American

Water Works Association and the New England Water Works Association. Committee A21 was assigned the following scope:

> "Unification of specifications for cast iron pipe, including: materials; dimensions; pressure ratings; methods of manufacture (including such new developments as centrifugal casting), in so far as they may be necessary to secure satisfactory specifications; elimination of unnecessary sizes and varieties; consideration of the possibility of developing a coordinated scheme of metallic pipe and fittings applicable to all common mediums; and methods of making up joints in so far as they are determining as to the dimensional design of cast iron pipe.
>
> The types of cast iron pipe to include: bell and spigot pipe; flanged pipe; flanged and bell mouth fittings and wall castings; pipe elbows, tees, Y's, return bends and other fittings not now included in standard lists; cast iron pipe threaded for flanges or couplings; soil pipe and other light types of cast iron pipe and fittings. The standardization is not to include methods of installing pipe and similar matters, except as to the making up of joints in its relationship to the dimensional standardization of pipe and fittings, as noted above."

At the Committee's request soil pipe was assigned to another committee. Screw fittings have been omitted from the work of the Committee.

Specifications are being issued, simultaneously with this Manual, on Cast Iron Pit Cast Pipe for Water or Other Liquids (A.S.A. A21.2–1939) and on Cement Mortar Lining for Cast Iron Pipe and Fittings (A.S.A. A21.4–1939). Committee A21 has in preparation specifications on Cast Iron Pit Cast Pipe for Gas, on pipes other than pit cast, including pipe cast centrifugally, on Cast Iron Bell and Spigot Fittings, on Cast Iron Flanged Pipe and Fittings, and on Coal-Tar Dip Coating for Cast Iron Pipe and Fittings.

Committee A21 has had the benefit of a fund for tests and research, provided largely by the producers. Records of tests made and conclusions drawn have been or will be published in separate volumes. These tests include tests of corrosion of different kinds of cast iron; tests of pipe under combined earth and internal pressures, upon which designs of barrel of pipe have been based; tests of hydraulic friction losses in fittings; bursting tests of pipe and fittings; tests of holding strength and deflection of bell and spigot joints; tests of lugs and harness for bell and spigot joints; tests of welded clips for use with harness. The publications already issued and those projected are listed.

Publications Developed under the Committee's Direction

Investigation of Bell and Spigot Joints in Cast Iron Pipe. By John C. Prior, January, 1935, being Bulletin No. 87, Engineering Experiment Station, Ohio State University; 57 pages, price 50 cents.
Part 1—Pull Out Strength; Part 2—Bell Strength; Part 3—Harness Strength.
Note: Work participated in by Cast Iron Pipe Research Association, City of Columbus, Ohio, and Committee A21.

Long versus Short Body Fittings for Water Supply.
Part I—Loss of Head Caused by Bends, Tees and Crosses. By Ernest W. Schoder and Arthur N. Vanderlip.
Part II—Economic Comparison. By Allen T. Ricketts and Thos. H. Wiggin
Cornell University Engineering Experiment Station, Bulletin No. 20, September, 1935. 102 pages; Price $1.25.

Report of Tests to Determine the Shearing Strength of Steel Anchor Clips Bronze Welded to Cast Iron Pipe.
By W. J. Krefeld, Engineer of Tests, Civil Engineering Laboratories, Columbia University in New York City, with Memorandum by Leonard P. Wood of Committee A21. Published in 1936 by Committee A21, 18 pp., 25 cents.

Strength and Elastic Properties of Cast Iron.
By W. J. Schlick and Bernard A. Moore. Bulletin 127, Iowa Engineering Experiment Station, June, 1936; 95 pages.
(Note: Work described was mostly not done for Committee A21 but was related to it, done in same period and shows some correlations with results of work done for Committee A21.)

Publications Projected

Bulletin of University of Illinois, Engineering Experiment Station, describing bursting tests, beam tests and many other miscellaneous tests on cast iron pipe and fittings. By Dean M. L. Enger.

Bulletin of Iowa State College, describing tests of cast iron pipe supported in various ways and with exterior loads only or with various combinations of exterior load and interior pressure applied simultaneously. By W. J. Schlick.

Corrosion Tests of Cast Iron of Various Chemical Compositions.
Work done at Massachusetts Institute of Technology.

From the tests and research a new theory of design was developed in which not only static water pressure and water hammer but also earth pressure and load from trucks are included in computations for thickness; also different methods of laying, i.e., pipe supported on blocks or on trench bottom, with or without tamping of backfill and with various depths of earth cover. The specifications (A21.2 – 1939) give thicknesses for some of these laying conditions. This Manual describes the principles and methods of computing pipe thicknesess, and of estimating trench and truck loads.

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* Deceased.

† Deceased, L. P. Wood, Acting Chairman.

PREFACE

This Manual is intended primarily to explain the new principles and methods which have been used by Sectional Committee A21 in the computation of standard pipe thicknesses which are included with the specifications for pit cast and other types of cast iron pipe. These principles and methods are of general application to cast iron of any strength and Part 1 of the Manual shows how the methods may be used to compute the necessary thickness of a pipe under known conditions of internal pressure, earth cover and method of laying, for any specified strength of iron.

Diagrams of earth load, truck super load, ratio to 3-edge bearing and other data used in computing and fixing thicknesses in the specifications, as well as data which may be used for conditions other than those covered by the specifications, are included in the Manual.

In Part 2 of the Manual the particular application of the methods for computing barrel thickness described in Part 1 is made to Cast Iron Pit Cast Pipe, cast with iron having the strength assumed in the specifications therefor; and Appendix 2A of Part 2 gives extended tables of thickness for Cast Iron Pit Cast Pipe for Water or Other Liquids. These extended tables include a greater range of cover than Tables 1 through 4 of the specifications and also include thicknesses for two additional methods of laying which are little used as yet but are of possible interest to the pipe-user under certain special conditions. Additional parts of the Manual containing data on other types of pipe will be issued when specifications for the other types of pipe are completed.

It is the intention to add to the Manual any data which the Committee shall believe necessary for a proper understanding and use of any of the specifications for straight pipe, for fittings or for coatings which may be produced by the Committee in fulfilment of its assigned scope or for intelligent use of the Manual.

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MANUAL

Part 1

Method of Computing Thickness of Barrel of Cast Iron Pipe

Sect. 1-1. New Factors in Design of Cast Iron Pipe

The method used in computing thickness of pipe in the schedules contained in the specifications of which this Manual is explanatory is based both on tests made for Sectional Committee A21 and on many earlier tests made at the Iowa State College on sewer pipe and culverts. The earlier tests developed the magnitude of the backfill loads transmitted to pipe laid in ditches or under road embankments, and of the load added by vehicles superimposed on the backfill, also the effect of various methods of supporting the pipe and the effect of tamping and not tamping the backfill.

The tests made for Committee A21 carried the Iowa State College investigations a step further by the inclusion of internal pressure applied simultaneously with external earth load to pipe supported in various ways and with backfill tamped and not tamped. An additional method of support, beyond those previously included at Iowa State College was introduced, viz., by blocking which is used by some constructors for water and gas pipe but not used for sewer pipe.

Sect. 1-2. Methods of Laying, or "Field Conditions," Considered

Four common and two uncommon methods of laying cast iron water pipe and gas pipe were selected as covering conditions met with at present or likely ever to be met with in case of pipe laid in trenches having approximately vertical sides. These were named "field conditions" and are as shown on the following page.

FIELD CONDITIONS

Field Condition	Explanation
A	Flat bottom trench, backfilling not tamped.
B	Flat bottom trench, backfilling tamped.
C	Pipe supported on blocks, backfilling not tamped.
D	Pipe supported on blocks, backfilling tamped.
E	Bottom of trench shaped to fit bottom of pipe for about 90° (unevennesses filled in by sand as required), backfilling not tamped.
F	Same as E except that backfilling is tamped

Field conditions E and F are common for sewer pipe but have been rarely used for cast iron water and gas pipe though the superior strength of pipe so laid has caused some increase in the use of this practice for pipe lines.

Another condition, viz. pipe under embankment, will be treated in an appendix (not yet prepared).

Sect. 1-3. Law of Behavior of Pipe under Both External Load and Internal Pressure

The tests made for Committee A21 showed that, when a pipe has both an external load applied in 3-edge bearing (see Sections 1–4 and 1–5) and an internal pressure, the relation between the external load and the internal pressure at the point of breaking can be represented with sufficient accuracy for various combinations of internal pressure and trench load by a parabola drawn as in Fig. 1.

The load-pressure curve (Fig. 1), employed either graphically or algebraically by use of its equation, is the basis of the whole system of barrel thickness computation used by Com. A21. It was initially the work of Prof. W. J. Schlick of Iowa State College, the institution employed by Com. A21 to make its tests on combined earth load and internal pressure.

Sect. 1-4. Equation of Load-Pressure Parabola and Values of Constants in Equation

The equation of the load-pressure parabola may be expressed,

$$w = \frac{W}{\sqrt{P}} \sqrt{P - p}$$

where the letters signify quantities in relation to the parabola as explained in Sect. 1–3 and Fig. 1. A definite equation may be written for any pipe for which P and W are known and these may be computed from the formulae given below using breaking strengths determined by crushing and bursting tests.

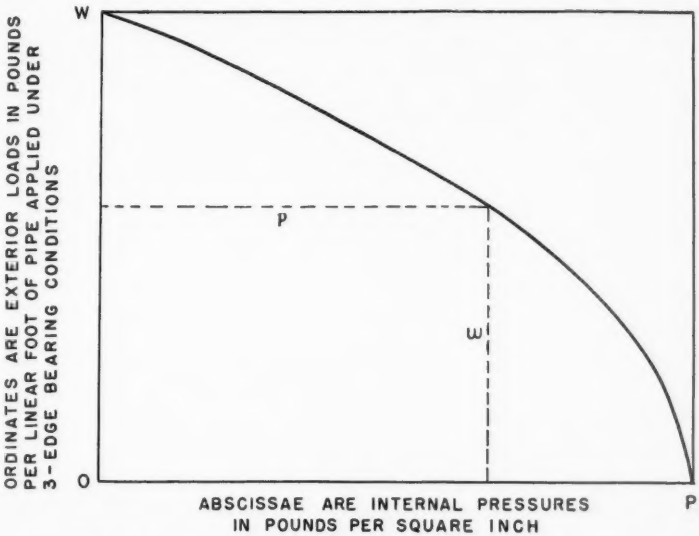

W
P
w
O
P
ORDINATES ARE EXTERIOR LOADS IN POUNDS PER LINEAR FOOT OF PIPE APPLIED UNDER 3-EDGE BEARING CONDITIONS
ABSCISSAE ARE INTERNAL PRESSURES IN POUNDS PER SQUARE INCH

FIG. 1. Load-Pressure Curve.
EXPLANATION: Load-Pressure Curve is a parabola with apex at P. P is the bursting pressure of the pipe when no earth load exists. W is the crushing load per linear foot of pipe in 3-edge bearing when no internal pressure exists. p and w are any combination of internal pressure and external load which will just cause fracture. For equation of parabola and values of P and W see Sect. 1-4.

P, the bursting pressure of the pipe in lb. per sq.in., is found by the usual cylinder formula,

$$P = \frac{2tS}{d}$$

where t is the thickness of the pipe in inches,

S is the bursting strength in lb. per sq.in. of the metal in the pipe, as determined by bursting tests of full lengths of pipe having metal of the same kind.

d is the internal diameter of the pipe in inches.

W, the crushing load in lb. per lin. ft. of pipe supported in 3-edge bearing, is found by the following formula.

$$W = \frac{t^2R}{.0795\ (d + t)}$$ **

where t is the thickness of the pipe in inches,
d is the internal diameter of the pipe in inches,

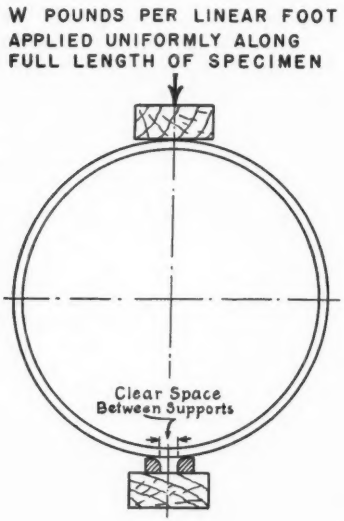


FIG. 2

NOTE—The condition of loading shown in Fig. 2 is usually called, and is called in the specifications and Manual of Committee A21, the "three-edge bearing load" because two supports close together are used to facilitate the laboratory test work by keeping the specimen from rolling on the table of the testing machine.

and R is the modulus of rupture in lb. per sq.in. of the metal in the pipe as determined by crushing tests of specimens of pipe having metal of the same kind, the pipe being loaded as shown in Fig. 2.

** This formula is approximate since the deflection, y, is omitted, but is near enough for designing purposes. The accurate formula is:

$$W = \frac{t^2R}{.0795\ (d + t + 0.85y)}$$

It is often more convenient to use $(O.D. - t)$ instead of $(d + t)$.

p and w are any combination of internal pressure and external load which will just cause fracture. In the design of pipe thickness, p and w are quantities obtained by multiplying the internal water pressure and the earth load, each as determined by the condition under which the pipe is assumed to be used, by the desired factor of safety.

Sect. 1-5. Ratios to Three-Edge Bearing

As noted in Sections 1–3 and 1–4 the parabola described in those sections is for a pipe to which the exterior load and support are applied as in 3-edge bearing. This does not represent any field condition but is used as a convenient medium of computing for the field conditions, A, B, C, D, E and F, previously described. The factor or "ratio to 3-edge bearing" by which the trench load acting in each of these field conditions A to F must be divided so that the load thus altered will have *the same effect on a pipe subjected to 3-edge bearing as the actual load does on the pipe subjected to the given field condition,* has been determined with sufficient accuracy for design purposes and is shown in Fig. 3. In general terms it will be seen that all field conditions except C (blocks with no tamping) and D (blocks with tamping) are more favorable than 3-edge bearing in that the loads are to be divided by a ratio larger than unity.

Pipes laid on blocks, as in Field Conditions C and D, particularly C in which the fill is untamped, have the most unfavorable ratios. The ratios in these cases are less definite than for Field Conditions A, B, E and F because they are affected greatly by firmness of foundation under the blocks, firmness of tamping, size of blocks and hardness of the wood, and presence or absence of wedges which, when substantial, aid the strength by forming haunch supports. Values of the C ratio shown on Fig. 3 are for a rather severe condition and those for the D ratio an ordinary or average condition. In either case blocks are assumed to be spaced 6 feet apart on the average, i.e. two blocks per 12-foot length and a correspondingly greater number for longer lengths of pipe. *Greater average spacing will give more severe conditions to which the ratios are not applicable.*

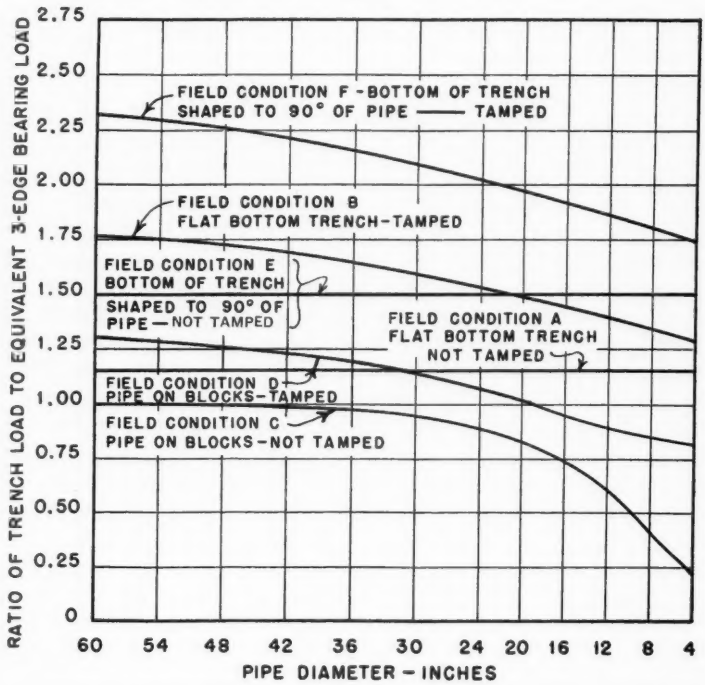
See Section 1–13 for the effect of beam action on thickness of smaller pipes spanning between blocks in Field Condition C.

Sect. 1-6. Forces Acting on Pipe When in Service

Cast iron or other pipe laid in the ground are acted on by one or more of the following forces:

1. Internal static pressure of the liquid or gas which is contained in the pipe.

2. Water hammer (or hammer from other liquid).
3. Load from the backfill.
4. Load and impact from passing trucks or other vehicles.


RATIO OF TRENCH LOAD TO EQUIVALENT 3-EDGE BEARING LOAD
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
FIELD CONDITION F - BOTTOM OF TRENCH SHAPED TO 90° OF PIPE —— TAMPED
FIELD CONDITION B FLAT BOTTOM TRENCH-TAMPED
FIELD CONDITION E BOTTOM OF TRENCH SHAPED TO 90° OF PIPE — NOT TAMPED
FIELD CONDITION A FLAT BOTTOM TRENCH NOT TAMPED
FIELD CONDITION D PIPE ON BLOCKS-TAMPED
FIELD CONDITION C PIPE ON BLOCKS-NOT TAMPED
60 54 48 42 36 30 24 20 16 12 8 4
PIPE DIAMETER - INCHES

SIZE	4"	6"	8"	10"	12"	14"	16"	18"	20"	24"	30"	36"	42"	48"	54"	60"
A	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
B	1.29	1.32	1.34	1.36	1.38	1.41	1.43	1.45	1.47	1.52	1.58	1.64	1.69	1.72	1.75	1.77
C	.22	.31	.40	.50	.60	.67	.73	.78	.81	.87	.93	.96	.98	.99	.99	1.00
D	.82	.83	.84	.86	.88	.91	.95	.98	1.01	1.07	1.14	1.19	1.23	1.25	1.28	1.31
E	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
F	1.75	1.78	1.80	1.83	1.85	1.88	1.90	1.93	1.95	2.00	2.08	2.14	2.20	2.25	2.29	2.31

Note: C and D ratios are for an average block spacing of 6 feet.

FIG. 3. Ratios to 3-edge Bearing

Loads 2 and 4 are occasional and transitory. In the specifications of Committee A21 they are not assumed as acting simultaneously but both are considered separately as loads added to static pressure and backfill load, and whichever of the two gives the greater computed

thickness of pipe, when taken together with the normal loads 1 and 3, is controlling in the determination of pipe thickness for the case under consideration.

Pipe for gas are free from the hammer caused by liquids and are hence always computed with truck load and its impact added to to the load from backfill.

Definite values of the above loads, obtained as explained in Sections 1–7, 1–8 and 1–9, are used in the parabolic curve, generally graphically, to obtain the computed pipe thicknesses.

Sect. 1-7. Water Pressure and Water Hammer

The static pressure will of course be known or assumed from conditions fixed by the pipe line design. The intensities of water hammer vary greatly according to types of gate valves, check valves and altitude valves; types of pump and power; presence or absence of automatic relief valves with effective quick acting controls; arrangement of pipe line, i.e., whether single or part of a grillage system; and other factors which it would require too much space to enumerate. Experiments on water hammer under the various usual conditions in which water pipe are used are few and Committee A21 has been unable from its inquiries to suggest improvements over the assumptions of water hammer made by the late Dexter Brackett, which have therefore been used in computing the thickness tables. They are listed in Table 1. *Each designer of a pipe line should consider whether the conditions in his case may need a more liberal water hammer allowance.*

TABLE 1

Allowances for Water Hammer

DIAM. OF PIPE, INCHES	WATER HAMMER, LB. PER SQ.IN.	DIAM. OF PIPE, INCHES	WATER HAMMER, LB. PER SQ.IN.
4 to 10	120	24	85
12 to 14	110	30	80
16 to 18	100	36	75
20	90	42 to 60	70

Sect. 1-8. Estimation of Earth Loads

Earth loads are computed by mathematical formulae developed at Iowa State College and based on full scale tests extending over a period of more than 25 years. The growth of this system of earth load estimation is to be found in Bulletins 31, 36, 47, 57, 76, 80, 96,

104, 108, 112 of the Engineering Experiment Station at Iowa State College. Simplified statements may be found in a paper by Wiggin, Enger and Schlick given before the American Water Works Association in April, 1938 (Jour. A. W. W. A., **31**: 841 (1939)) and in one by W. D. Moore before the American Water Works Association in June, 1939 (Jour. A. W. W. A., **31**: 1655 (1939)).

On account of the mathematical work involved in computing these loads, Committee A21 arranged with Professor Schlick to make or supervise the necessary computations of earth loads under several

TABLE 2

List of Fill-Load Diagrams

FIG. NO.	TRENCH		WEIGHT OF EARTH, LB. PER CU. FT.	FIELD CONDITIONS OF LAYING TO WHICH APPLICABLE
	Width	Slope of Sides		
4	d + 2 ft.	Vertical	120	A, B, C, E and F
5	d + 2 ft.	Vertical	120	D
6	d + 1 ft.	Vertical	120	A, B, C, D, E and F
7	See Diagram	1 on 1	110	A, B, C, D, E and F
8	See Diagram	2 on 1	120	A, B, C, D, E and F

Note 1. d is nominal diameter of pipe expressed in feet.

Note 2. Figures 4, 6, 7 and 8 are applicable to all field conditions, except D, by direct use of the curves. Figure 5 gives earth loads for Field Condition D with d + 2 ft. trench. For the d + 1 ft. trench and the sloping-sided trenches loads for Field Condition D are found by reading from the diagrams and applying the percentages given on the diagrams for condition D.

Note 3. This Manual does not include fill-load diagrams and tables of 3-edge bearing ratios for conditions produced when an embankment is placed over a pipe which is laid wholly or partly projecting from the base on which the embankment is subsequently deposited.

different conditions of trench width, slopes of sides of trench, methods of supporting the pipe and depths of cover. These computations have been used in preparing the diagrams listed in Table 2. Copies of these diagrams follow in this Manual.

The earth loads used in computing the thickness tables in Committee A21 work are shown on diagrams, Figures 4 and 5, listed in Table 2, i.e., for vertical-sided trench 2 feet wider than the nominal diameter of the pipe. Figures 6, 7 and 8 give fill-loads for use in design for three types of trench different from those assumed in computing the pipe thickness tables.

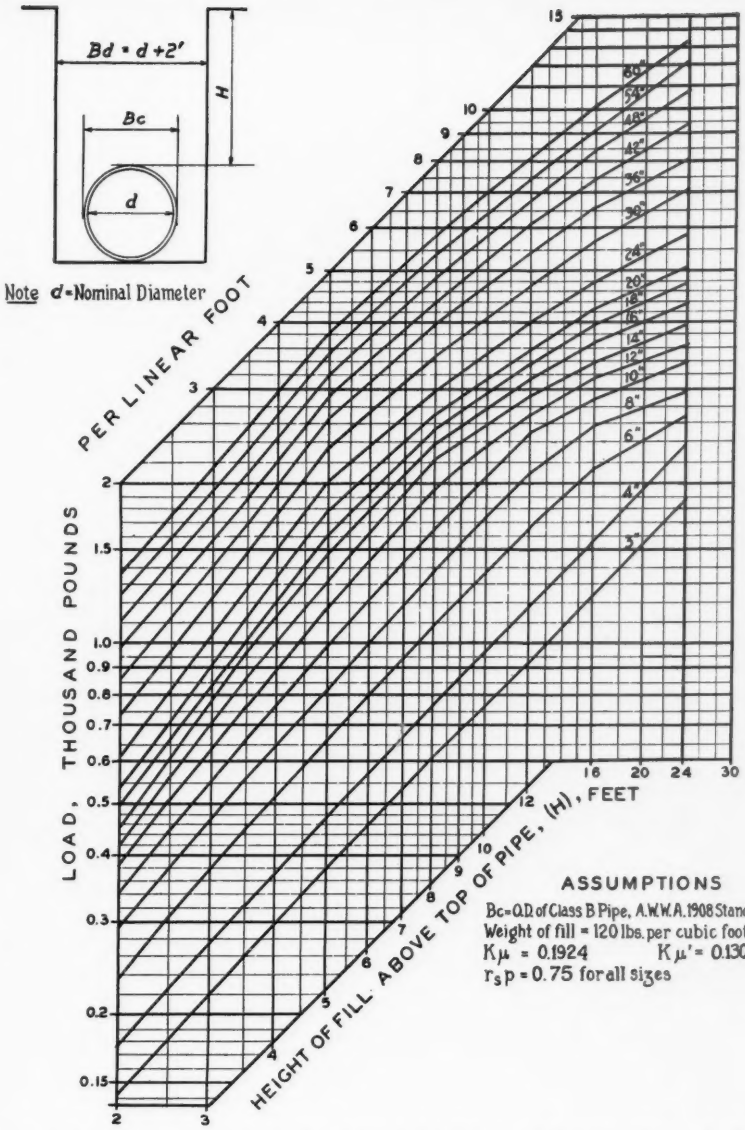

Bd = d + 2'
H
Bc
d
Note d'=Nominal Diameter
LOAD, THOUSAND POUNDS PER LINEAR FOOT
HEIGHT OF FILL ABOVE TOP OF PIPE, (H), FEET
ASSUMPTIONS
Bc=O.D. of Class B Pipe, A.W.W.A. 1908 Standard
Weight of fill = 120 lbs. per cubic foot
Kμ = 0.1924 Kμ' = 0.130
rsp = 0.75 for all sizes

FIG. 4. Fill Loads on Pipe for Width of Ditch d + 2 feet and Field Conditions A, B, C, E, and F

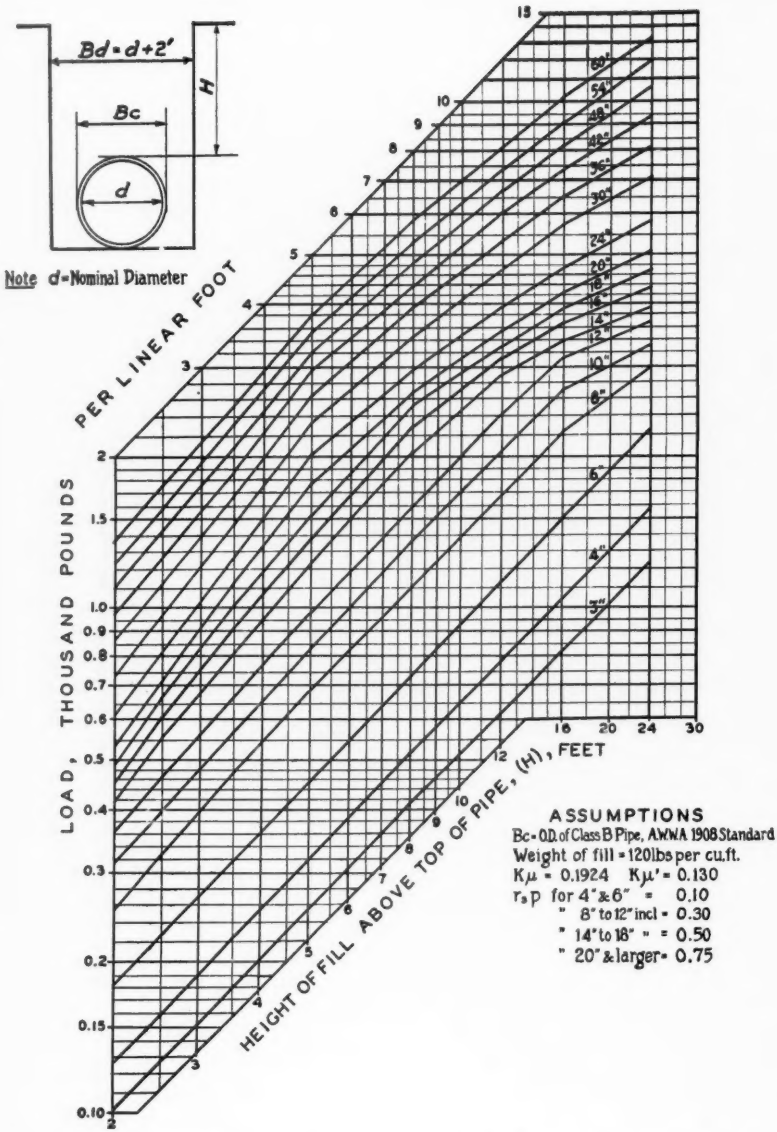
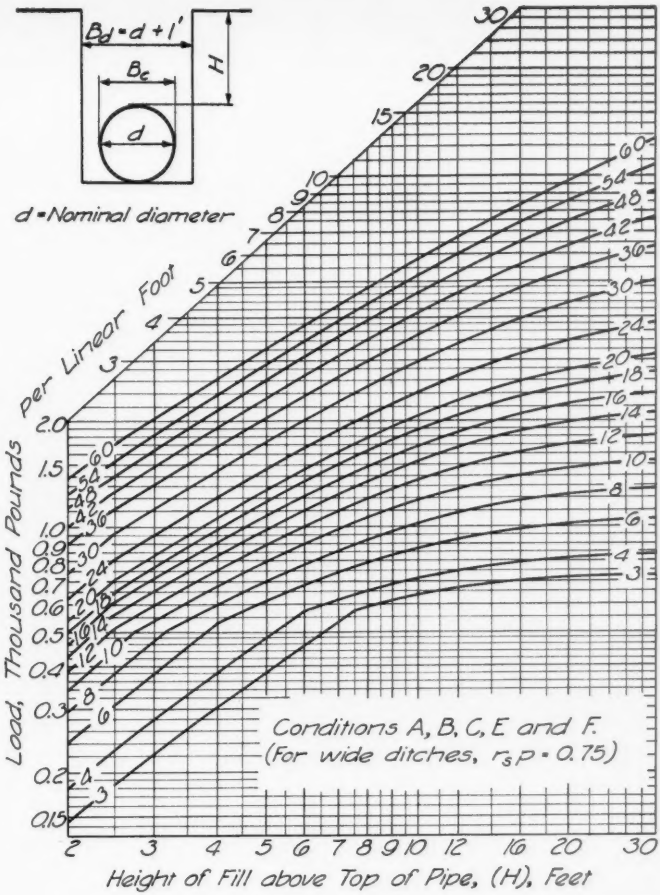

Bd = d+2'
Bc
H
d
Note d=Nominal Diameter
LOAD, THOUSAND POUNDS PER LINEAR FOOT
HEIGHT OF FILL ABOVE TOP OF PIPE, (H), FEET
ASSUMPTIONS
Bc = O.D. of Class B Pipe, AWWA 1908 Standard
Weight of fill = 120 lbs per cu.ft.
Kμ = 0.1924 Kμ' = 0.130
rsp for 4" & 6" = 0.10
" 8" to 12" incl = 0.30
" 14" to 18" " = 0.50
" 20" & larger = 0.75

FIG. 5. Fill Loads on Pipe for Width of Ditch d + 2 feet and Field Condition D


$B_d = d + 1'$
B_c
H
d
d = Nominal diameter
Load, Thousand Pounds per Linear Foot
Conditions A, B, C, E and F.
(For wide ditches, $r_s p = 0.75$)
Height of Fill above Top of Pipe, (H), Feet

Condition D

Size of pipe, inches	$r_s p$ for wide ditches	Percent of diagram load — Values of H, feet				
		2	5	10	18	30
3 to 6	0.10	70	70	95	100	100
8 to 12	0.30	90	100	100	100	100
14 to 18	0.50	100	100	100	100	100
20 & more	0.75	100	100	100	100	100

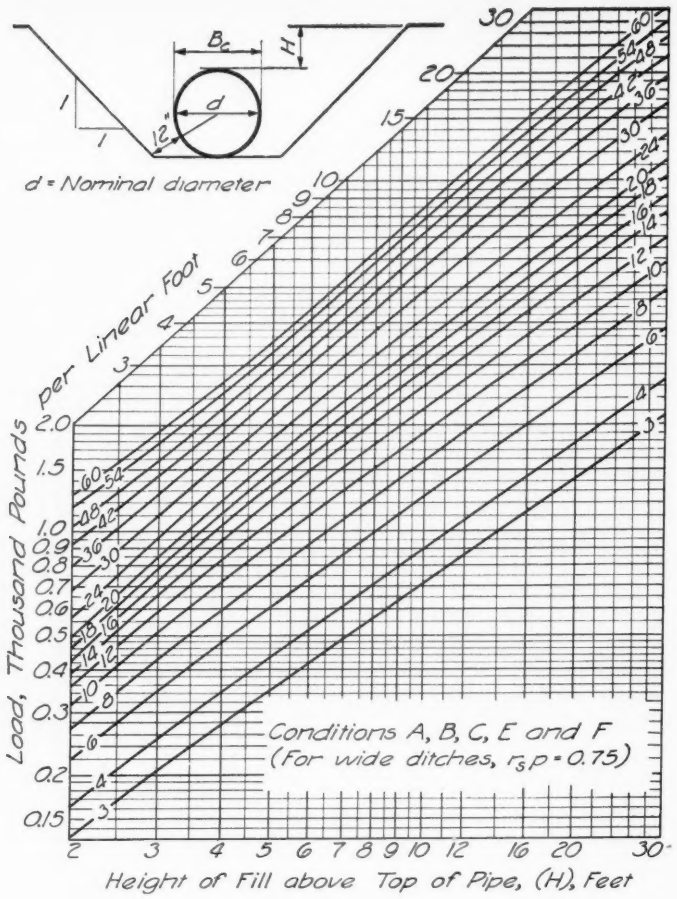
Fill Loads - Vertical Sided Ditch of Width $d + 1'$

For B_c = O.D. of Class B, A.W.W.A. 1908 Standards

W = unit weight of fill = 120 lb. per cu. ft.

$K\mu = 0.1924$ $K\mu' = 0.130$

Fig. 6. Fill Loads on Pipe for Width of Ditch d + 1 ft.



Condition D

Size of pipe, inches	$r_s p$ for wide ditches	Percent of diagram load				
		Values of H, feet				
		2	5	10	18	30
3 to 6	0.10	70	70	70	65	65
8 to 12	0.30	90	85	80	80	80
14 to 18	0.50	100	95	90	90	90
20 & more	0.75	100	100	100	100	100

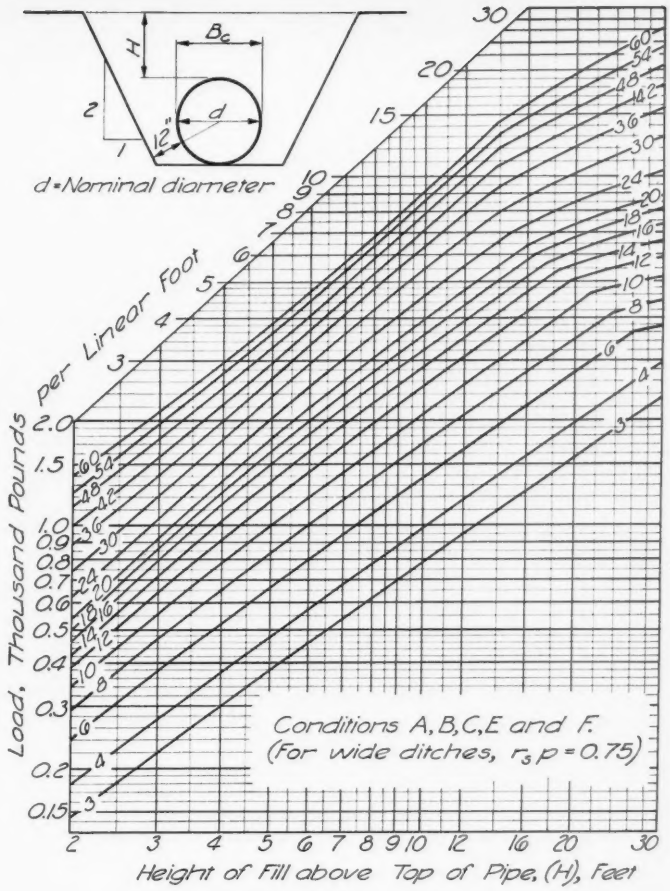
Fill Loads - Ditch with Sides Sloping 1 on 1

For B_c = O.D of Class B, A.W.W.A. 1908 Standards

W = unit weight of fill = 110 lb. per cu. ft.

$K\mu = 0.1924$ $K\mu' = 0.150$

FIG. 7. Fill Loads on Pipe for Ditches Having 1 on 1 Side Slopes



Condition D

Size of pipe, inches	$r_s p$ for wide ditches	Percent of diagram load — Values of H, feet				
		2	5	10	18	30
3 to 6	0.10	70	70	70	70	70
8 to 12	0.30	95	85	80	80	100
14 to 18	0.50	100	95	90	95	100
20 & more	0.75	100	100	100	100	100

Fill Loads - Ditch with Sides Sloping 2 on 1

For B_c = O.D. of Class B, A.W.W.A. 1908 Standards

W = unit weight of fill = 120 lb. per cu. ft.

$K\mu = 0.1924$ $K\mu' = 0.130$

Fig. 8. Fill Loads on Pipe for Ditches Having 2 on 1 Side Slopes

Sect. 1-9. Truck Superload and Impact

In computing pipe thicknesses, truck loads are added to earth loads in certain cases (see Sections 1-6 and 1-11, Sub-section (f)). Two passing trucks are assumed with rear axles both over the pipe at the same time, adjacent wheels of the two trucks 3 feet apart

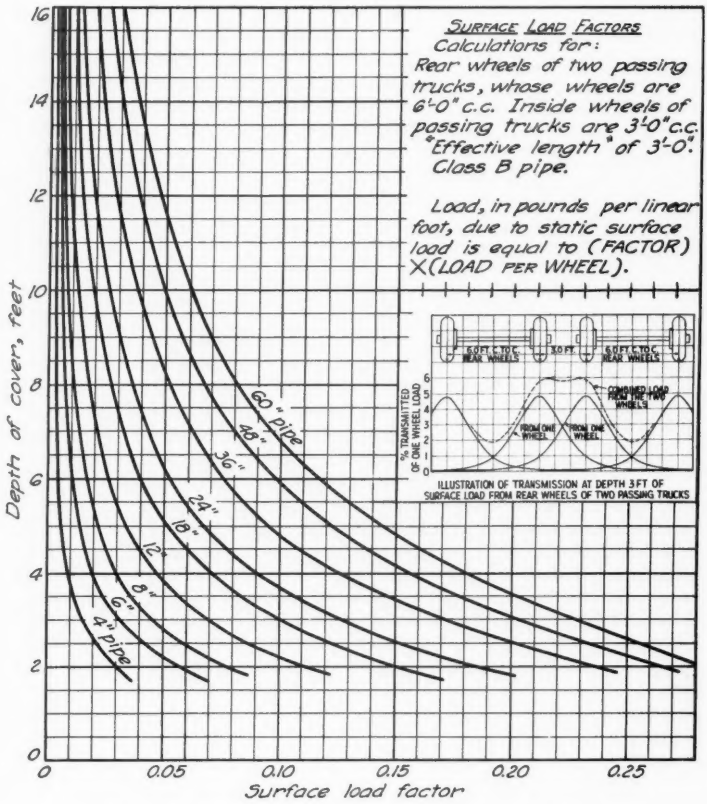


FIG. 9. Surface Load Factors for Two Passing Trucks

center to center, and load on each rear wheel 9,000 lb. To the load thus obtained 50 per cent is added for impact of the moving trucks over a road or trench surface assumed to be rough.

The proportion of a wheel load which is transmitted through the backfill to the pipe itself (the remainder being spread on either side

of the pipe) diminishes as depth of cover increases, and the length of pipe, over which the load which comes on the pipe is spread, increases with increase in depth of cover. These effects have been determined quantitatively by experiment at Iowa State College over a period of years and the results have been plotted by Prof. W. J. Schlick of that college for use of Committee A21. Figure 9 shows Prof. Schlick's diagram from which may be read the factors varying with size of pipe and depth of cover by which to multiply a single truck wheel load in order to give the average load per foot on the pipe from the two adjacent truck wheels placed three feet center to center along the pipe as above described.

On this diagram, Fig. 9, is a small sketch illustrating the distribution of this truck load along the pipe. In designing the pipe there

TABLE 3

DIAMETER OF PIPE, INCHES	PERCENTAGES OF TRUCK LOAD USED							
	2.5′–3.5′ Cover Field Cond.		4′–7′ Cover Field Cond.		8′–10′ Cover Field Cond.		Over 10′ Cover Field Cond.	
	A, B, E & F	C & D	A, B, E & F	C & D	A, B, E & F	C & D	A, B, E & F	C & D
4 to 12	100	78	100	84	100	90	100	95
14	92	78	100	84	100	90	100	95
16	88	78	95	84	100	90	100	95
18	85	78	90	84	100	90	100	95
20	83	78	90	84	95	90	100	95
24 to 30	81	78	85	84	95	90	100	95
36 to 60	80	78	85	84	90	90	100	95

are reductions to be made in the truck loads determined as above described. With field conditions C and D, in each of which the pipe is supported on blocks, the truck load, which is of intensity indicated by the diagram only over a few feet of the pipe, gives less load on the blocks than if the truck load were continuous over at least two lengths of the pipe. Similarly with field conditions A, B, E, and F the parts of the pipe which receive the truck load in its full intensity are aided in carrying the load by adjacent parts of the pipe which receive less load or no load from the trucks. These effects have been studied in detail by the Committee and the ameliorating effects estimated as given in Table 3.

The use of Table 3 is illustrated in the examples of actual design of pipe given in Section 1–11, Sub-section (g).

Sect. 1-10. The Factors of Safety

The factors of safety assumed by Committee A21 in computing pipe thicknesses are as follows:

For external loads.....2.5
For internal pressure....2.5

These factors of safety are necessarily chosen arbitrarily. They are considerably lower than the factor of safety which was formerly thought to exist for cast iron pipe but that was when only water pressure and water hammer were considered. The factors of safety were chosen of a magnitude which would result in thicknesses for pipe under ordinary conditions of use, which have been found satisfactory under those conditions, considering both American and foreign experience but giving more weight to American experience. The foreign standards are generally thinner than American standards for the same service.

It will be seen in Sect. 1–12 that the factor of safety is in effect generally made higher for pipe 8 inches and less in diameter for ordinary pressures and depths of cover, because their computed thicknesses are smaller than experience shows to be safe for handling, so that greater thicknesses are used arbitrarily.

Sect. 1-11. Details of Applying Method of Computing Net Barrel Thickness, with Illustrations

(a) *Net Thickness Defined; Additions to Net Thickness for Foundry Tolerance and Corrosion.* Section 1–11 relates especially to computation of *net thickness.* Net thickness is assumed in this Manual to mean the thickness available for resisting the external loads and internal pressures to which the pipe may be subjected. The net thicknesses computed in accordance with the following sub-sections are to be increased by the additions below noted in order to obtain the total or gross thickness.

(1) Foundry tolerance permitted below standard thickness.

(2) Corrosion allowance.

These additions to thickness, being different in total magnitude for pipes manufactured by different methods, are treated in detail in subsequent parts of the Manual which are devoted each to a separate type or group of types of pipe; e.g., see Part 2 for Cast Iron Pit Cast Pipe.

(b) *Equation Used and Data Required.* In computing net barrel thicknesses of cast iron pipe the equation for the load-pressure

parabola explained in Sect. 1–4 is used. This equation in convenient form for use is

$$w = \frac{W}{\sqrt{P}} \sqrt{P - p}, \text{ where}$$

w, W, p & P have the significance explained in Sect. 1–4.

The problem is generally as follows:
Given:

(1) Nominal diameter of pipe, d, inches
(2) Assumed width of trench, feet
(3) Cover, or depth of fill over pipe, feet
(4) Assumed Field Condition, i e. A, B, C, D, E or F.
(5) Maximum static pressure expected to occur in service, lb. per sq.in.
(6) Assumed magnitude of water hammer, lb. per sq.in.
(7) Assumed strength of iron in bursting pipe, S, lb. per sq.in.
(8) Assumed strength of iron in crushing of pipe as a ring, R, lb. per sq.in.
(9) Factor of safety.

Required: to find the necessary thickness of the pipe.

(c) *Graphical Method Described.* The easiest approach to the problem is to assume two or three different net thicknesses, varying by $\frac{1}{10}$ inch, covering the range within which the thickness to be determined is expected to lie. Plot the load-pressure curves for each of these thicknesses on the same diagram, using the same co-ordinate axes. Then plot a single point on the same diagram with the p and w (see Sect. 1–3, Fig. 1) for the given conditions as co-ordinates. The thickness is obtained by interpolation. Figures 10, 11, and 12 illustrate three methods of making such diagrams.

(d) *First Graphical Method—Load Pressure Parabolas Plotted to Natural Scale (Fig. 10).* The first method, shown on Fig. 10, is to draw the load-pressure parabolas to natural scale. They can be drawn when the values of P and W for each assumed thickness have been computed in the manner explained in Sect. 1–4, P being the abscissa of the vertex of the parabola and W being the ordinate with abscissa zero. The remainder of each parabola is located by plotting back from a vertical line through the vertex of the parabola three intermediate points with the fractional abscissae $\frac{1}{16}$ P, $\frac{4}{16}$ P, and $\frac{9}{16}$ P, the corresponding ordinates being $\frac{1}{4}$ W, $\frac{1}{2}$ W, and $\frac{3}{4}$ W respectively. If preferred, the intermediate points may be obtained

from the equation of the parabola, assuming values of p in round numbers and computing the corresponding values of w.

(e) *Second Graphical Method—Load-Pressure Parabolas Plotted as Straight Lines (Fig. 11).* The second method of plotting, shown in Fig. 11, is by use of a special scale of ordinates in which the plotted length of each ordinate is the square of the actual length. This

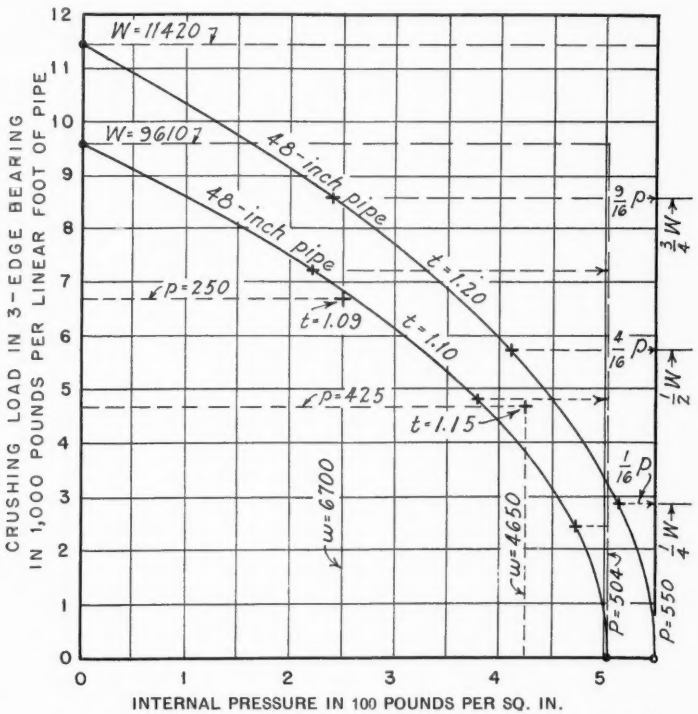


FIG. 10. Determining Thickness of Cast Iron Pipe by Parabolic Load-Pressure Curves Drawn to Natural Scale; 48-inch Pipe Used as Sample

makes the parabolas plot as straight lines which can be drawn at once when the values of P and W are known for each parabola. Standard forms like Fig. 11 were used extensively in thickness computations for Committee A21 and are applicable in the solution of any problem with any assumptions as to unit strengths of iron (S and R) or other conditions. For computation of the many cases required for tables of thickness with constant values of S and R,

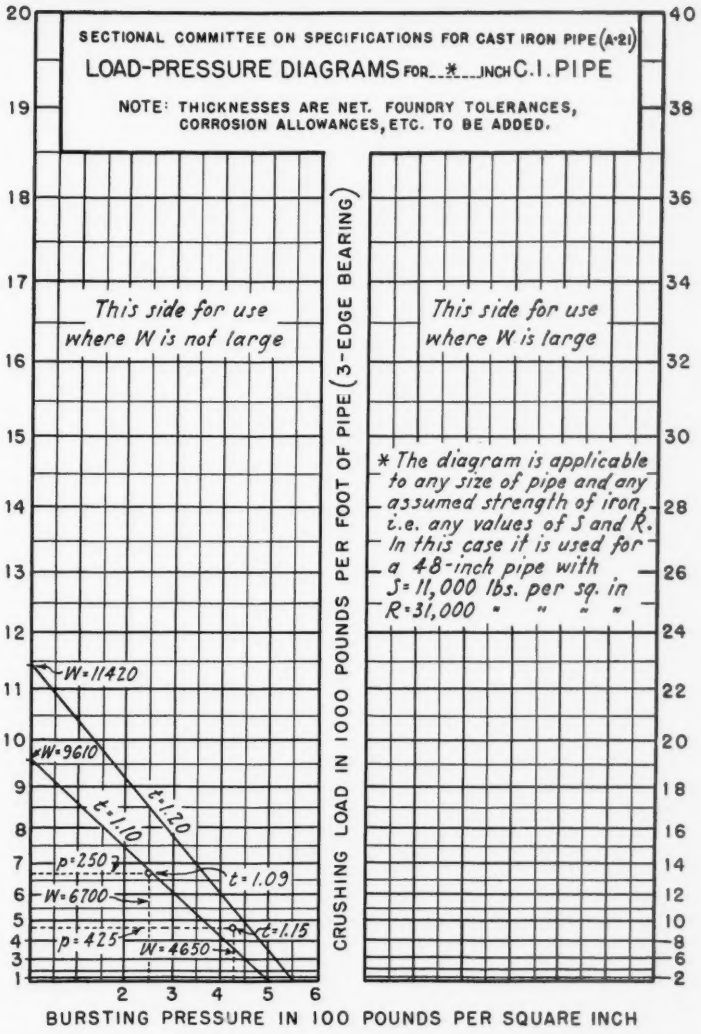

SECTIONAL COMMITTEE ON SPECIFICATIONS FOR CAST IRON PIPE (A-21)
LOAD-PRESSURE DIAGRAMS FOR * INCH C.I. PIPE
NOTE: THICKNESSES ARE NET. FOUNDRY TOLERANCES, CORROSION ALLOWANCES, ETC. TO BE ADDED.
This side for use where W is not large
This side for use where W is large
* The diagram is applicable to any size of pipe and any assumed strength of iron, i.e. any values of S and R. In this case it is used for a 48-inch pipe with S = 11,000 lbs. per sq. in R = 31,000 " " " "
W = 11420
W = 9610
t = 1.20
t = 1.10
p = 250
t = 1.09
W = 6700
t = 1.15
p = 425
W = 4650
CRUSHING LOAD IN 1000 POUNDS PER FOOT OF PIPE (3-EDGE BEARING)
BURSTING PRESSURE IN 100 POUNDS PER SQUARE INCH

FIG. 11. Determining Thickness of Cast Iron Pipe by Load-Pressure Parabolas Drawn as Straight Lines; 48-inch Pipe Used as Sample

the method shown in Fig. 12, explained below, is much more expeditious and was used in the final tables of thicknesses submitted by Committee A21.

(f) *Third Graphical Method—Nomogram* (*Fig. 12*). In this third graphical method shown in Fig. 12, definite thickness points are plotted between which the desired thickness may be obtained by interpolation. As in Fig. 11, the external load scale (at left in Fig. 12) is one in which the vertical distance from zero is plotted as a height equal to the *square* of the exterior load which is actually marked on the scale. The internal pressure scale (at the right in Fig. 12) is a natural scale.

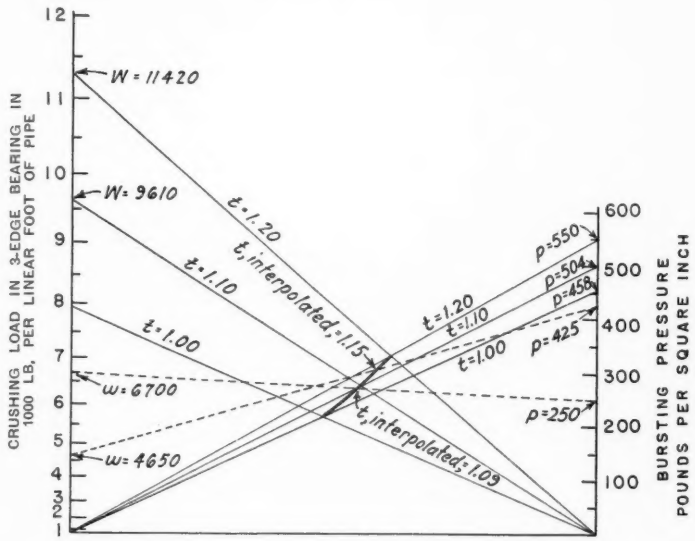


FIG. 12. Determining Thickness of Cast Iron Pipe by Nomogram Method; 48-inch Pipe Used as Sample

Such a diagram, in blank, with the exterior load and the interior pressure scale constructed as above described, may be used, as may Fig. 11, to plot any two or more thicknesses (computed with any specified values of S and R) between which to interpolate for solving any problem in barrel thickness computation by the Committee A21 method. The particular diagram or nomogram shown as Fig. 12 shows merely three definite thickness points between which interpolation for a single problem has been made but Figures 2.1, 2.2 and 2.3 in Part 2 show thickness points covering a wide range of thicknesses for pipes from 3 inches to 60 inches in diameter, for iron having S = 11,000 and R = 31,000 pounds per square inch.

This type of nomogram, devised by C. K. Donoho of the American Cast Iron Pipe Company, is the best method yet known for general use. With a group of such nomograms for each desired pair of corresponding values for S and R any net thickness may be read by a single application of a straight edge between known points p and w which have been determined for the particular problem.

(g) *A concrete example* is worked out below by each of the three methods.

The Example:

Nominal diameter of pipe	48 inches
Trench width	$d + 2' = 6$ ft.
Cover	5 ft.
Method of laying	Field Condition B
Static pressure	100 lb. per sq.in.
Water hammer—as in Sect. 1–7	70 lb. per sq.in.
Strength of iron in bursting pipe	$S = 11{,}000$ lb. per sq.in.
Strength of iron in crushing of pipe as a ring	$R = 31{,}000$ lb. per sq.in.
Factor of safety	2.5

To find required net barrel thickness.

Solution:

Fill load per lin. ft. of pipe, (Fig. 4)	3,200 lb.
Truck load (Fig. 9), $0.1225 \times 9000 = 1100$	
Add for impact $50\% =$ 550	
1650	
Percent. of Truck Load used (Table in Sect. 1–9) 85% of 1650	= 1,400
Fill load plus truck load	4,600

Since the load-pressure curve is applicable only when exterior loads are transformed to loads in 3-edge bearing (see 1–5 and Fig. 3) the fill load of 3200 and the fill load plus truck load are to be reduced by dividing by the 3-edge ratio for 48-inch pipe with B condition of loading. This ratio is 1.72 (see Fig. 3).

3-edge bearing load equivalent to fill-load = $3200/1.72 = 1860$

3-edge bearing load equivalent to fill load + truck load = $4600/1.72 = 2680$

Case 1. Water Hammer Assumed but No Truck Load.

The pipe is to be designed so that it will just break when subjected simultaneously to:

p = (static pressure plus water hammer) $\times$ factor of safety 2.5 and

w = (3-edge bearing load equivalent to fill load) $\times$ factor of safety 2.5

In this case: $p = (100 + 70) \times 2.5 = 425$

$w = 1860 \times 2.5 = 4650$

Case 2. Truck Load Assumed but no Water Hammer.

The pipe is to be designed so that it will just break when subjected simultaneously to:

p = static pressure $\times$ factor of safety 2.5

w = (3-edge bearing load equivalent to fill load plus truck load) multiplied by factor of safety 2.5

In this case: $p = 100 \times 2.5 = 250$

$w = 2680 \times 2.5 = 6700$

The values of p and w in Cases 1 and 2 are to be plotted on diagrams to be constructed by the three methods described in subsections (d), (e), and (f) above. Two arbitrary pipe thicknesses will be assumed in making these diagrams, viz. 1.10 and 1.20.

For $t = 1.10$:

$$P = \frac{2tS}{d} \text{ (Sect. M4)} = \frac{2 \times 1.10 \times 11000}{48} = 504$$

$$W = \frac{t^2R}{.0795\,(d+t)} \text{ (Sect. M4)} = \frac{(1.10)^2 \times 31{,}000}{.0795 \times 49.1} = 9{,}610$$

For $t = 1.20$:

$$P = \frac{2 \times 1.20 \times 11000}{48} = \ldots\ldots\ldots\ldots\ldots\ldots \quad 550$$

$$W = \frac{(1.20)^2 \times 31{,}000}{.0795 \times 49.2} = \ldots\ldots\ldots\ldots\ldots\ldots \quad 11{,}420$$

With the above values of P and W the parabolas for $t = 1.10$ and $t = 1.20$, respectively, are plotted as curves on Fig. 10 and as straight lines on Fig. 11. On Fig. 12 the two definite thickness points, viz. for $t = 1.10$ and $t = 1.20$, are plotted by the intersection

of two lines as shown, and in order to make the shape of the thickness curve for the 48-inch pipe more evident, a third point has been added for $t = 1.00$ with P and W 458 and 7960 respectively, computed in the same manner as shown previously for $t = 1.10$ and $t = 1.20$.

Interpolations are made on each of the three diagrams by using values of p and w for Case 1 and Case 2 computed above on page 22. The same results are seen to be obtained from all three diagrams and are as follows:

For Case 1, assuming water hammer but no truck load, the plotted point falls about half way between the load-pressure lines for $t = 1.10$ and $t = 1.20$, and by this interpolation ..... $t = 1.15$

For Case 2, assuming truck load but no water hammer, the plotted point falls just below the load-pressure line for $t = 1.10$, giving ..... $t = 1.09$

The nomogram, Fig. 12, gives the same results.

The water hammer assumption is hence controlling and the net design thickness is ..... $t = 1.15$

For a gas pipe, where water hammer is absent, Case 2 only would be computed and the net thickness would be ..... $t = 1.09$

(h) *Net Thickness Increased by Foundry Tolerance and Corrosion Allowance.* To each of the net thicknesses computed in Sub-section (g) above, are to be added foundry tolerance and corrosion allowance, which, for 48-inch pit cast pipe, have been assumed by Committee A21 as .10 and .08 inch respectively. These additions will make the thicknesses as follows:

For water pipe, $1.15 + .10 + .08 = 1.33$
For gas pipe, $1.09 + .10 + .08 = 1.27$

By reference to the Manual, Part 2, Appendix 2A, table 2A.2, page 17, it will be noted that the calculated thickness of a 48-inch water pipe for 100 lb. pressure and 5 foot cover is 1.33, though, as explained in Part 2, the standard thickness is made 1.37 which is the nearest standard thickness class. The standard thickness class for the above gas pipe is 1.27.

Sect. 1-12. Arbitrary Minimum Thickness, when Greater than Computed Thickness, Used Instead of Computed Thickness

Irrespective of calculated thickness, no standard thickness is made less than a certain minimum thickness for the particular diameter and kind of iron. This minimum thickness is chosen by judgment with due regard to shocks received by the pipe in handling and transporting. This provision controls thicknesses of 3-inch and 4-inch pipe for most pressures and covers, controls thicknesses of 6-inch and 8-inch under most of the ordinary conditions of pressure and cover, and controls thicknesses of 12-inch and 14-inch pipe under a few of the lighter pressures and covers.

As these minimum thicknesses vary for pipe made by different processes, they are treated in detail for each kind of pipe in the appropriate part of the Manual, e.g., Pit Cast Pipe in Part 2.

Sect. 1-13. Beam Conditions Control Thicknesses of Smaller Pipe with Field Condition C unless Blocks are Favorably Spaced

A pipe supported on blocks with untamped backfill acts as a beam spanning between the blocks to a greater or less extent depending on the hardness of the foundation under the blocks, the size and hardness of the blocks themselves, also the stiffness of the pipe as a beam and the degree to which some supporting fill happens to run under the pipe between blocks. The only safe assumption is to assume conditions giving unreduced beam action. For the smaller pipe, 3-inch to 8-inch inclusive, it has been found necessary to investigate the pipe as beams. Wherever the thickness of the pipe computed as a beam, using the net thickness as defined in Sect. 1–11, Sub-sect. (a), is greater than that determined by the methods described in Sect. 1–11 and 1–12, the beam thickness is used.

Spacing of blocks affects greatly the stresses caused by beam action. The most favorable location for two blocks under a 12-foot length of pipe is approximately 30-inches from each end of the pipe. With such a spacing, the 3-inch size is the only one (of those included in the thickness tables) in which the thicknesses are affected by beam conditions and then only with earth covers over about 10-feet. For other spacing of blocks, thicknesses of 4-inch, 6-inch and 8-inch pipe may be affected. Tables 2A.3 and 2B.3 in Appendices 2A and 2B, in Part 2 of the Manual, show these effects in detail for pit cast pipe. Corresponding tables for other types of pipe will show similar data for such types of pipe.

Sect. 1-14. To Compute Factor of Safety of a Given Pipe

The formula for load-pressure relationship can be used to compute factors of safety when thickness of pipe is known. Two examples are given below.

Example 1

For convenience in checking results, the same example, a 48-inch pit cast pipe, that was used in Sect. 1–11 to illustrate methods of computing barrel thickness, will be reversed by using the thickness therein computed (see Sect. 1–11, Sub-sect. (g), and finding its factor of safety. Case 1, assuming water hammer and no truck load, will be used. Field Condition B will be assumed as before.

The necessary thickness to order from the foundry was computed as 1.33. If the particular length were of minimum thickness permitted under the specifications, 1.23, and had further corroded so as to have a loss in strength equal to that which would be produced by making it 0.08 inch thinner, its net thickness would be 1.15.

For a 48-inch pit cast pipe of thickness 1.15, made of iron having $S = 11{,}000$ and $R = 31{,}000$,

$$P = \frac{2tS}{d} = \frac{2 \times 1.15 \times 11{,}000}{48} = 527 \text{ lb. per sq.in.}$$

$$W = \frac{t^2R}{.0795\,(d+t)} = \frac{(1.15)^2 \times 31{,}000}{.0795 \times 49.15} = 10{,}490 \text{ lb.}$$

The formula for the load-pressure curve is:

$$w = \frac{W}{\sqrt{P}}\sqrt{P - p}$$

In this case W and P have the values computed above, and, if we call the unknown factor of safety x, w has the value $1860x$ (see page 21 for the 1860) and p has the value $170x$ (see page 22 for 170).

The factor of safety is found algebraically as shown below. By substituting the above values in the above formula the equation becomes:

$$\begin{aligned}
1860x &= \frac{10490}{\sqrt{527}}\sqrt{527 - 170x} \\
1860x &= 457.5\sqrt{527 - 170x} \\
x &= .246\sqrt{527 - 170x} \\
x^2 &= .0605\,(527 - 170x) \\
x^2 &= 31.9 - 10.3x \\
x &= -5.15 + \sqrt{31.9 + (5.15)^2} \\
x &= -5.15 + \sqrt{58.4} = -5.15 + 7.64 \\
x &= 2.49
\end{aligned}$$

Since the factor of safety used in the original example was 2.5, a good check is afforded by the 2.49 obtained above.

Example 2

This example is to find what factor of safety the same 48-inch pipe with net thickness of 1.15 would have, assuming the same loading and internal pressure, if it were laid on blocks with untamped backfill.

By reference to Fig. 3, the ratio to 3-edge bearing is found to be 0.99. The 3-edge bearing load equivalent to the fill load will be:

$3200/.99 = 3230$, instead of:

$3200/1.72 = 1860$, as in the previous example.

All other values in the formula remain as in Example 1 above and the equation becomes:

$$3230x = \frac{10490}{\sqrt{527}}\sqrt{527 - 170x}$$

$$3230x = 457.5\sqrt{527 - 170x}$$

$$x = .1413\sqrt{527 - 170x}$$

$$x^2 = .0200\,(527 - 170x)$$

$$x^2 = 10.54 - 3.40x$$

$$x = -1.70 + \sqrt{10.54 + (1.7)^2}$$

$$x = -1.70 + \sqrt{13.43} = -1.70 + 3.66$$

$$x = 1.96$$

That is, the factor of safety in this case is reduced from 2.5 to 1.96 by using blocks with untamped backfill instead of flat bottomed trench, with tamped backfill.

MANUAL FOR THE COMPUTATION OF STRENGTH AND THICKNESS OF CAST IRON PIPE

PART 2

with

Comprehensive Tables

Of Calculated and Standard Barrel Thicknesses

For Pit Cast Pipe for Water or Other Liquids

All Computations Based on: S=11,000 lb. per sq.in. and R=31,000 lb. per sq.in.

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MANUAL

Part 2

Cast Iron Pit Cast Pipe

Sect. 2A-1. Introductory Statement; Unit Strength of Iron

Calculated thicknesses given in the comprehensive tables in Appendices 2A and 2B are computed by the method described in the Manual Part 1, using unit strengths of pit cast pipe iron which comply with the specifications for Cast Iron Pit Cast Pipe for Water or Other Liquids and with the specifications for Cast Iron Pit Cast Pipe for Gas. These unit strengths are as follows:

S, Bursting Strength, = 11,000 lb. per sq.in.
R, Crushing Strength, = 31,000 lb. per sq.in.

Figures 2.1, 2.2 and 2.3 are the nomograms by use of which the necessary net thickness may be determined for any pipe from 3-inch to 60-inch inclusive, made of 11000–31000 cast iron, and, within the limits of the diagrams, for any internal pressure and any exterior equivalent 3-edge load. The use of these nomograms is described in the Manual, Part 1, Section 1–11, Sub-sections (f) and (g) and Fig. 12. The three nomograms, Figures 2.1, 2.2 and 2.3, with varying scales, are needed to cover the full range of conditions. One diagram, made to sufficiently large scale to permit reading the smaller loads, would be very large because of the fact that the squares of the loads are plotted.

Sect. 2A-2. Additions to Net Computed Thicknesses to Obtain Calculated Thicknesses

Calculated thicknesses are obtained by adding to net thickness computed by the parabolic formula the following constants:

(a) Maximum foundry tolerances permitted by the specifications;
(b) Corrosion allowance of .08 inch.

Maximum foundry tolerances are as follows:

Diameters Inches	Maximum Foundry Tolerances Inches
3 to 8 inclusive	.07
10 to 24 inclusive	.08
30 to 60 inclusive	.10

Sect. 2A-3. Minimum Thicknesses of Pipe

Irrespective of calculated thicknesses no standard thickness is made less than the minima shown in Table 2.1, chosen by judgment with due regard to shocks received by the pipe in handling and transporting.

Sect. 2A-4. Standard Thickness Classes

Calculated thicknesses are not used exactly but the Standard Thickness Class, from the Table 2.2, nearest to the calculated thickness (or the next thicker standard thickness class in case the calculated thickness is halfway between two standard thicknesses) is used in order to avoid an endless number of different thicknesses varying by small intervals.

TABLE 2.1

Minimum Thicknesses for Cast Iron Pit Cast Pipe

DIAMETER OF PIPE, INCHES	MINIMUM THICKNESS, INCHES
3	.37
4	.40
6	.43
8	.46
10	.50
12	.54
Larger than 12	As computed for 50 lb. static pressure plus water hammer, with trench load for cover of 5 feet and Field Condition B.**

** Note: In cases of the 24″, 36″, 54″, and 60″ pipe, there is a difference of .01 inch between the minimum computed as above and the actual minimum used.

TABLE 2.2

Standard Thickness Classes for Pit Cast Pipe

NOMINAL DIAMETER, INCHES	NUMBER AND PIPE WALL THICKNESSES OF STANDARD THICKNESS CLASSES													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3	.37	.40	.43	.46	.50	.54	.58	.63	.68	.73	.79	.85	.92	.99
4	.40	.43	.46	.50	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07
6	.43	.46	.50	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16
8	.46	.50	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25
10	.50	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25	1.35
12	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25	1.35	1.46
14	.54	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25	1.35	1.46
16	.58	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25	1.35	1.46	1.58
18	.63	.68	.73	.79	.85	.92	.99	1.07	1.16	1.25	1.35	1.46	1.58	1.71
20	.66	.71	.77	.83	.90	.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79
24	.74	.80	.86	.93	1.00	1.08	1.17	1.26	1.36	1.47	1.59	1.72	1.86	2.01
30	.87	.94	1.02	1.10	1.19	1.29	1.39	1.50	1.62	1.75	1.89	2.04	2.20	2.38
36	.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79	1.93	2.08	2.25	2.43	2.62
42	1.07	1.16	1.25	1.35	1.46	1.58	1.71	1.85	2.00	2.16	2.33	2.52	2.72	2.94
48	1.18	1.27	1.37	1.48	1.60	1.73	1.87	2.02	2.18	2.35	2.54	2.74	2.96	3.20
54	1.30	1.40	1.51	1.63	1.76	1.90	2.05	2.21	2.39	2.58	2.79	3.01	3.25	3.51
60	1.39	1.50	1.62	1.75	1.89	2.04	2.20	2.38	2.57	2.78	3.00	3.24	3.50	3.78

Each class is made 8 per cent heavier than the preceding class, starting with class 1 as the base class. Class 1 is fixed as in Table 2.1 above.

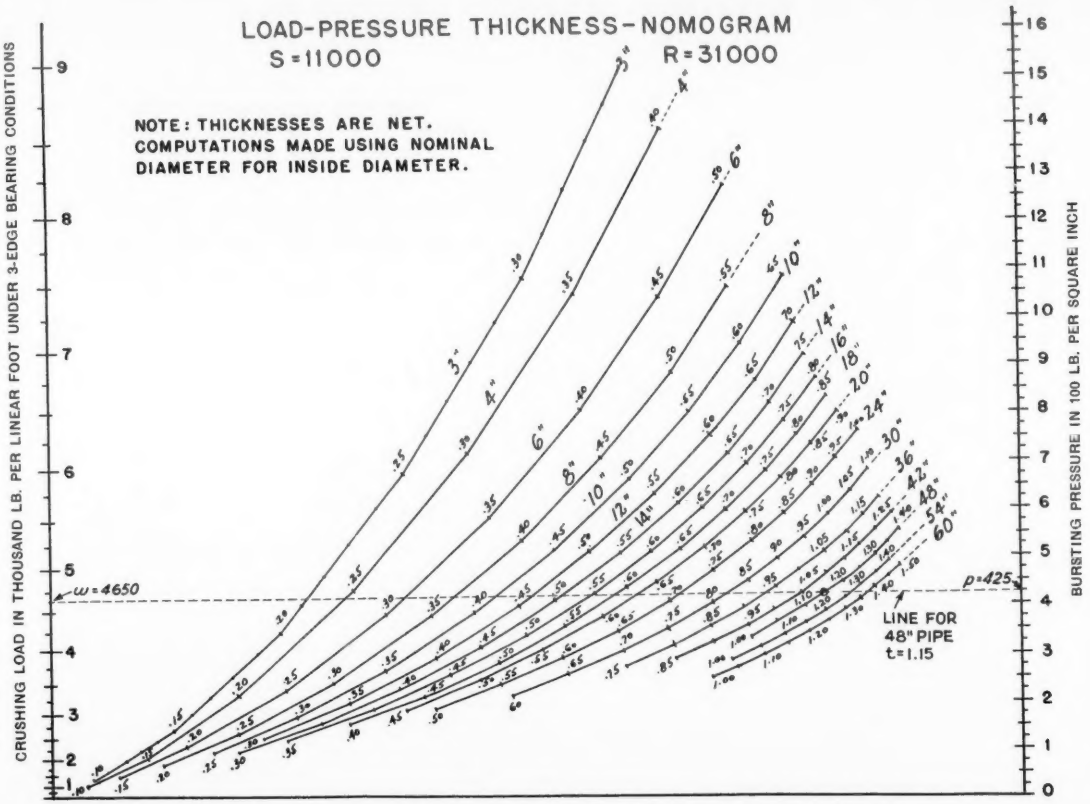


FIG. 2.1. Nomogram. See Example in Sect. 1-11 (g) and Fig. 12 in Manual.

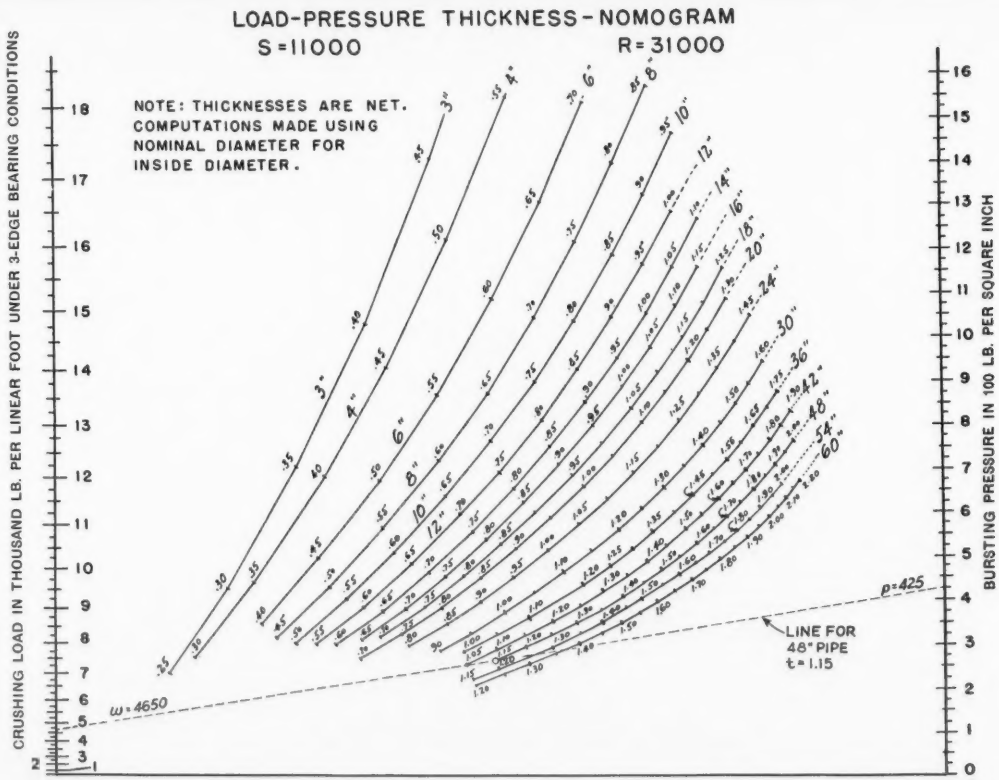

LOAD-PRESSURE THICKNESS-NOMOGRAM
S=11000
R=31000
NOTE: THICKNESSES ARE NET. COMPUTATIONS MADE USING NOMINAL DIAMETER FOR INSIDE DIAMETER.
CRUSHING LOAD IN THOUSAND LB. PER LINEAR FOOT UNDER 3-EDGE BEARING CONDITIONS
BURSTING PRESSURE IN 100 LB. PER SQUARE INCH
w=4650
p=425
LINE FOR 48" PIPE t=1.15

FIG. 2.2. Nomogram. See Example in Sect. 1–11 (g) and Fig. 12 in Manual.

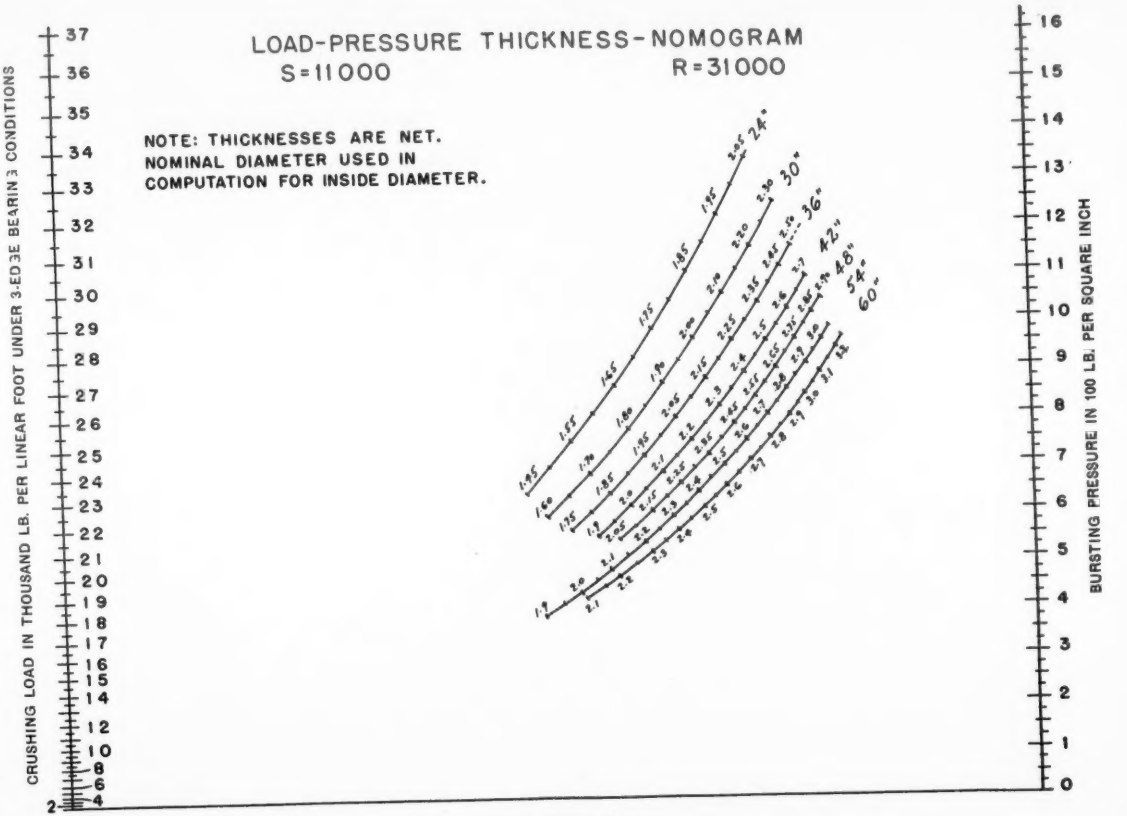

LOAD-PRESSURE THICKNESS-NOMOGRAM
S=11000
R=31000
NOTE: THICKNESSES ARE NET.
NOMINAL DIAMETER USED IN
COMPUTATION FOR INSIDE DIAMETER.
CRUSHING LOAD IN THOUSAND LB. PER LINEAR FOOT UNDER 3-EDGE BEARING CONDITIONS
BURSTING PRESSURE IN 100 LB. PER SQUARE INCH
24"
30"
36"
42"
48"
54"
60"

FIG. 2.3

APPENDIX 2A

TABLE 2A.1*

Schedule of Barrel Thicknesses—Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	3½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	5	Calc. Thick.	.25	.26	.26	.27	.29	.31	.32
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	8	Calc. Thick.	.27	.27	.29	.30	.31	.32	.33
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	12	Calc. Thick.	.29	.30	.31	.32	.33	.34	.35
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	16	Calc. Thick.	.31	.32	.33	.34	.35	.35	.36
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
4	2½	Calc. Thick.	*.27	*.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	3½	Calc. Thick.	*.27	*.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	5	Calc. Thick.	.29	.30	.31	.32	.34	.36	.38
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	8	Calc. Thick.	.31	.32	.33	.34	.35	.37	.39
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	12	Calc. Thick.	.34	.35	.36	.37	.38	.40	.41
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	16	Calc. Thick.	.37	.37	.38	.39	.40	.41	.43
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.40	.40	.40	.40	.40	.40	.43
6	2½	Calc. Thick.	*.33	*.34	*.35	*.37	.41	.44	.47
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.43	.43	.43	.43	.43	.43	.46
	3½	Calc. Thick.	*.32	*.33	.36	.38	.41	.46	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	5	Calc. Thick.	.34	.36	.38	.40	.42	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	8	Calc. Thick.	.38	.40	.41	.43	.45	.48	.51
		Use Thickness Class.	1	1	1	1	2	3	3
		Use Thickness.	.43	.43	.43	.43	.46	.50	.50
	12	Calc. Thick.	.42	.44	.45	.47	.49	.51	.53
		Use Thickness Class.	1	1	2	2	3	3	4
		Use Thickness.	.43	.43	.46	.46	.50	.50	.54
	16	Calc. Thick.	.46	.48	.49	.51	.52	.54	.56
		Use Thickness Class.	2	3	3	3	4	4	5
		Use Thickness.	.46	.50	.50	.50	.54	.54	.58

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.1 (*cont'd*)

Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
8	2½	Calc. Thick.	*.39	*.40	*.42	.46	.50	.54	.58
		Use {Thickness Class.	1	1	1	1	2	3	4
		Use {Thickness.	.46	.46	.46	.46	.50	.54	.58
	3½	Calc. Thick.	*.38	*.40	.43	.46	.50	.54	.59
		Use {Thickness Class.	1	1	1	1	2	3	4
		Use {Thickness.	.46	.46	.46	.46	.50	.54	.58
	5	Calc. Thick.	.41	.43	.46	.49	.52	.56	.60
		Use {Thickness Class.	1	1	1	2	3	4	4
		Use {Thickness.	.46	.46	.46	.50	.54	.58	.58
	8	Calc. Thick.	.45	.47	.49	.52	.55	.58	.61
		Use {Thickness Class.	1	1	2	3	3	4	5
		Use {Thickness.	.46	.46	.50	.54	.54	.58	.63
	12	Calc. Thick.	.51	.52	.55	.57	.60	.62	.65
		Use {Thickness Class.	2	3	3	4	4	5	5
		Use {Thickness.	.50	.54	.54	.58	.58	.63	.63
	16	Calc. Thick.	.55	.56	.58	.60	.63	.65	.68
		Use {Thickness Class.	3	4	4	4	5	5	6
		Use {Thickness.	.54	.58	.58	.58	.63	.63	.68
10	2½	Calc. Thick.	*.46	*.48	*.50	.54	.58	.64	.69
		Use {Thickness Class.	1	1	1	2	3	4	5
		Use {Thickness.	.50	.50	.50	.54	.58	.63	.68
	3½	Calc. Thick.	*.44	*.46	.50	.55	.60	.65	.70
		Use {Thickness Class.	1	1	1	2	3	4	5
		Use {Thickness.	.50	.50	.50	.54	.58	.63	.68
	5	Calc. Thick.	.47	.50	.53	.57	.62	.66	.71
		Use {Thickness Class.	1	1	2	3	4	5	6
		Use {Thickness.	.50	.50	.54	.58	.63	.68	.73
	8	Calc. Thick.	.53	.56	.59	.62	.66	.70	.74
		Use {Thickness Class.	2	3	3	4	5	5	6
		Use {Thickness.	.54	.58	.58	.63	.68	.68	.73
	12	Calc. Thick.	.60	.62	.65	.68	.71	.74	.78
		Use {Thickness Class.	3	4	4	5	6	6	7
		Use {Thickness.	.58	.63	.63	.68	.73	.73	.79
	16	Calc. Thick.	.63	.65	.67	.70	.73	.76	.80
		Use {Thickness Class.	4	4	5	5	6	7	7
		Use {Thickness.	.63	.63	.68	.68	.73	.79	.79
12	2½	Calc. Thick.	*.51	*.53	*.56	*.60	.66	.72	.79
		Use {Thickness Class.	1	1	2	2	4	5	6
		Use {Thickness.	.54	.54	.58	.58	.68	.73	.79
	3½	Calc. Thick.	*.49	*.52	.56	.61	.67	.73	.80
		Use {Thickness Class.	1	1	2	3	4	5	6
		Use {Thickness.	.54	.54	.58	.63	.68	.73	.79
	5	Calc. Thick.	.52	.55	.59	.64	.70	.75	.81
		Use {Thickness Class.	1	1	2	3	4	5	6
		Use {Thickness.	.54	.54	.58	.63	.68	.73	.79
	8	Calc. Thick.	.60	.63	.66	.70	.74	.79	.84
		Use {Thickness Class.	2	3	4	4	5	6	7
		Use {Thickness.	.58	.63	.68	.68	.73	.79	.85
	12	Calc. Thick.	.66	.69	.72	.75	.79	.84	.88
		Use {Thickness Class.	4	4	5	5	6	7	7
		Use {Thickness.	.68	.68	.73	.73	.79	.85	.85
	16	Calc. Thick.	.69	.72	.75	.78	.82	.86	.91
		Use {Thickness Class.	4	5	5	6	7	7	8
		Use {Thickness.	.68	.73	.73	.79	.85	.85	.92

TABLE 2A.1 (*cont'd*)

Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
14	2½	Calc. Thick.	*.55	*.58	*.61	.67	.75	.82	.90
		Use Thickness Class.	1	2	3	4	5	7	8
		Use Thickness.	.54	.58	.63	.68	.73	.85	.92
	3½	Calc. Thick.	*.54	*.57	.62	.69	.76	.83	.90
		Use Thickness Class.	1	2	3	4	6	7	8
		Use Thickness.	.54	.58	.63	.68	.79	.85	.92
	5	Calc. Thick.	.57	.61	.66	.72	.78	.84	.92
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.58	.63	.68	.73	.79	.85	.92
	8	Calc. Thick.	.67	.70	.75	.79	.84	.90	.96
		Use Thickness Class.	4	4	5	6	7	8	9
		Use Thickness.	.68	.68	.73	.79	.85	.92	.99
	12	Calc. Thick.	.73	.76	.80	.83	.88	.93	.99
		Use Thickness Class.	5	6	6	7	7	8	9
		Use Thickness.	.73	.79	.79	.85	.85	.92	.99
	16	Calc. Thick.	.76	.79	.83	.87	.91	.96	1.01
		Use Thickness Class.	6	6	7	7	8	9	9
		Use Thickness.	.79	.79	.85	.85	.92	.99	.99
16	2½	Calc. Thick.	*.60	*.62	*.66	.72	.81	.90	.98
		Use Thickness Class.	1	2	3	4	5	7	8
		Use Thickness.	.58	.63	.68	.73	.79	.92	.99
	3½	Calc. Thick.	*.59	*.62	.67	.74	.82	.91	.99
		Use Thickness Class.	1	2	3	4	5	7	8
		Use Thickness.	.58	.63	.68	.73	.79	.92	.99
	5	Calc. Thick.	*.62	.66	.72	.78	.85	.93	1.00
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.63	.68	.73	.79	.85	.92	.99
	8	Calc. Thick.	.71	.75	.80	.85	.91	.97	1.04
		Use Thickness Class.	4	4	5	6	7	8	9
		Use Thickness.	.73	.73	.79	.85	.92	.99	1.07
	12	Calc. Thick.	.78	.82	.86	.91	.96	1.01	1.08
		Use Thickness Class.	5	6	6	7	8	8	9
		Use Thickness.	.79	.85	.85	.02	.99	.99	1.07
	16	Calc. Thick.	.83	.86	.90	.94	.99	1.05	1.11
		Use Thickness Class.	6	6	7	7	8	9	9
		Use Thickness.	.85	.85	.92	.92	.99	1.07	1.07
18	2½	Calc. Thick.	*.65	*.68	.71	.79	.88	.98	1.08
		Use Thickness Class.	1	2	3	4	5	7	8
		Use Thickness.	.63	.68	.73	.79	.85	.99	1.07
	3½	Calc. Thick.	*.64	*.67	.73	.81	.90	.99	1.09
		Use Thickness Class.	1	2	3	4	6	7	8
		Use Thickness.	.63	.68	.73	.79	.92	.99	1.07
	5	Calc. Thick.	*.67	.73	.79	.86	.94	1.02	1.11
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.68	.73	.79	.85	.92	.99	1.07
	8	Calc. Thick.	.77	.82	.87	.93	1.00	1.07	1.15
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.79	.85	.85	.92	.99	1.07	1.16
	12	Calc. Thick.	.84	.89	.93	.98	1.05	1.11	1.19
		Use Thickness Class.	5	6	6	7	8	8	9
		Use Thickness.	.85	.92	.92	.99	1.07	1.07	1.16
	16	Calc. Thick.	.89	.93	.98	1.03	1.09	1.15	1.22
		Use Thickness Class.	6	6	7	8	8	9	10
		Use Thickness.	.92	.92	.99	1.07	1.07	1.16	1.25

TABLE 2A.1 (*cont'd*)

Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
20	2½	Calc. Thick.	*.69	*.72	*.77	.84	.94	1.06	1.16
		Use Thickness Class.	2	2	3	4	6	7	8
		Use Thickness.	.71	.71	.77	.83	.97	1.05	1.13
	3½	Calc. Thick.	*.68	*.72	.78	.86	.96	1.07	1.18
		Use Thickness Class.	1	2	3	4	6	7	9
		Use Thickness.	.66	.71	.77	.83	.97	1.05	1.22
	5	Calc. Thick.	.72	.77	.83	.91	1.00	1.11	1.20
		Use Thickness Class.	2	3	4	5	6	8	9
		Use Thickness.	.71	.77	.83	.90	.97	1.13	1.22
	8	Calc. Thick.	.81	.86	.92	.98	1.06	1.14	1.24
		Use Thickness Class.	4	4	5	6	7	8	9
		Use Thickness.	.83	.83	.90	.97	1.05	1.13	1.22
	12	Calc. Thick.	.90	.94	.99	1.06	1.12	1.20	1.28
		Use Thickness Class.	5	6	6	7	8	9	10
		Use Thickness.	.90	.97	.97	1.05	1.13	1.22	1.32
	16	Calc. Thick.	.95	1.00	1.05	1.10	1.17	1.24	1.32
		Use Thickness Class.	6	6	7	8	9	9	10
		Use Thickness.	.97	.97	1.05	1.13	1.22	1.22	1.32
24	2½	Calc. Thick.	*.78	*.82	*.87	.96	1.08	1.21	1.35
		Use Thickness Class.	2	2	3	4	6	7	9
		Use Thickness.	.80	.80	.86	.93	1.08	1.17	1.36
	3½	Calc. Thick.	*.76	*.81	.88	.99	1.11	1.23	1.36
		Use Thickness Class.	1	2	3	5	6	8	9
		Use Thickness.	.74	.80	.86	1.00	1.08	1.26	1.36
	5	Calc. Thick.	*.81	.87	.95	1.05	1.16	1.26	1.38
		Use Thickness Class.	2	3	4	6	7	8	9
		Use Thickness.	.80	.86	.93	1.08	1.17	1.26	1.36
	8	Calc. Thick.	.92	.98	1.05	1.13	1.22	1.32	1.43
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	.93	1.00	1.08	1.17	1.26	1.36	1.47
	12	Calc. Thick.	1.01	1.07	1.13	1.20	1.28	1.38	1.48
		Use Thickness Class.	5	6	7	7	8	9	10
		Use Thickness.	1.00	1.08	1.17	1.17	1.26	1.36	1.47
	16	Calc. Thick.	1.08	1.13	1.19	1.26	1.34	1.43	1.52
		Use Thickness Class.	6	7	7	8	9	10	10
		Use Thickness.	1.08	1.17	1.17	1.26	1.36	1.47	1.47
30	2½	Calc. Thick.	*.91	*.97	*1.05	1.17	1.32	1.48	1.65
		Use Thickness Class.	2	2	3	5	6	8	9
		Use Thickness.	.94	.94	1.02	1.19	1.29	1.50	1.62
	3½	Calc. Thick.	*.91	*.97	1.06	1.20	1.33	1.50	1.66
		Use Thickness Class.	2	2	4	5	6	8	9
		Use Thickness.	.94	.94	1.10	1.19	1.29	1.50	1.62
	5	Calc. Thick.	*.97	1.05	1.15	1.26	1.39	1.53	1.68
		Use Thickness Class.	2	3	5	6	7	8	9
		Use Thickness.	.94	1.02	1.19	1.29	1.39	1.50	1.62
	8	Calc. Thick.	1.09	1.17	1.25	1.35	1.47	1.60	1.74
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	1.10	1.19	1.29	1.39	1.50	1.62	1.75
	12	Calc. Thick.	1.21	1.28	1.36	1.45	1.56	1.67	1.80
		Use Thickness Class.	5	6	7	8	9	9	10
		Use Thickness.	1.19	1.29	1.39	1.50	1.62	1.62	1.75
	16	Calc. Thick.	1.30	1.37	1.45	1.53	1.63	1.74	1.85
		Use Thickness Class.	6	7	8	8	9	10	11
		Use Thickness.	1.29	1.39	1.50	1.50	1.62	1.75	1.89

TABLE 2A.1 (*cont'd*)

Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
36	2½	Calc. Thick.	*1.04	*1.11	*1.19	1.34	1.53	1.72	1.93
		Use Thickness Class.	2	3	4	5	7	8	10
		Use Thickness.	1.05	1.13	1.22	1.32	1.54	1.66	1.93
	3½	Calc. Thick.	*1.04	*1.11	1.20	1.37	1.55	1.73	1.94
		Use Thickness Class.	2	3	4	5	7	9	10
		Use Thickness.	1.05	1.13	1.22	1.32	1.54	1.79	1.93
	5	Calc. Thick.	*1.08	*1.18	1.32	1.43	1.60	1.76	1.95
		Use Thickness Class.	2	4	5	6	8	9	10
		Use Thickness.	1.05	1.22	1.32	1.43	1.66	1.79	1.93
	8	Calc. Thick.	1.24	1.33	1.43	1.56	1.70	1.85	2.03
		Use Thickness Class.	4	5	6	7	8	9	11
		Use Thickness.	1.22	1.32	1.43	1.54	1.66	1.79	2.08
	12	Calc. Thick.	1.39	1.47	1.57	1.67	1.80	1.94	2.10
		Use Thickness Class.	6	6	7	8	9	10	11
		Use Thickness.	1.43	1.43	1.54	1.66	1.79	1.93	2.08
	16	Calc. Thick.	1.50	1.57	1.66	1.77	1.88	2.03	2.16
		Use Thickness Class.	7	7	8	9	10	11	11
		Use Thickness.	1.54	1.54	1.66	1.79	1.93	2.08	2.08
42	2½	Calc. Thick.	*1.16	*1.24	*1.34	1.50	1.75	1.95	2.20
		Use Thickness Class.	2	3	4	5	7	9	10
		Use Thickness.	1.16	1.25	1.35	1.46	1.71	2.00	2.16
	3½	Calc. Thick.	*1.16	*1.24	1.35	1.54	1.76	1.97	2.22
		Use Thickness Class.	2	3	4	6	7	9	10
		Use Thickness.	1.16	1.25	1.35	1.58	1.71	2.00	2.16
	5	Calc. Thick.	*1.24	*1.32	1.46	1.63	1.81	2.02	2.25
		Use Thickness Class.	3	4	5	6	8	9	11
		Use Thickness.	1.25	1.35	1.46	1.58	1.85	2.00	2.33
	8	Calc. Thick.	1.38	1.48	1.60	1.74	1.92	2.08	2.33
		Use Thickness Class.	4	5	6	7	8	10	11
		Use Thickness.	1.35	1.46	1.58	1.71	1.85	2.16	2.33
	12	Calc. Thick.	1.56	1.65	1.76	1.89	2.04	2.22	2.39
		Use Thickness Class.	6	7	7	8	9	10	11
		Use Thickness.	1.58	1.71	1.71	1.85	2.00	2.16	2.33
	16	Calc. Thick.	1.69	1.78	1.88	2.00	2.15	2.30	2.46
		Use Thickness Class.	7	8	8	9	10	11	12
		Use Thickness.	1.71	1.85	1.85	2.00	2.16	2.33	2.52
48	2½	Calc. Thick.	*1.28	*1.38	*1.48	1.69	1.96	2.22	2.50
		Use Thickness Class.	2	3	4	6	8	9	11
		Use Thickness.	1.27	1.37	1.48	1.73	2.02	2.18	2.54
	3½	Calc. Thick.	*1.29	*1.38	1.52	1.74	1.98	2.23	2.51
		Use Thickness Class.	2	3	4	6	8	9	11
		Use Thickness.	1.27	1.37	1.48	1.73	2.02	2.18	2.54
	5	Calc. Thick.	*1.38	*1.47	1.64	1.83	2.05	2.28	2.54
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.37	1.48	1.60	1.87	2.02	2.35	2.54
	8	Calc. Thick.	1.54	1.67	1.80	1.95	2.15	2.38	2.62
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.60	1.73	1.87	2.02	2.18	2.35	2.54
	12	Calc. Thick.	1.74	1.84	1.97	2.12	2.33	2.60	2.72
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	1.73	1.87	2.02	2.18	2.35	2.54	2.74
	16	Calc. Thick.	1.90	2.00	2.12	2.24	2.42	2.55	2.75
		Use Thickness Class.	7	8	9	9	10	11	12
		Use Thickness.	1.87	2.02	2.18	2.18	2.35	2.54	2.74

TABLE 2A.1 (*cont'd*)

Field Condition A

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
54	2½	Calc. Thick.	*1.40	*1.51	*1.63	1.88	2.18	2.48	2.78
		Use Thickness Class.	2	3	4	6	8	9	11
		Use Thickness.	1.40	1.51	1.63	1.90	2.21	2.39	2.79
	3½	Calc. Thick.	*1.43	*1.53	*1.67	1.93	2.20	2.53	2.80
		Use Thickness Class.	2	3	4	6	8	10	11
		Use Thickness.	1.40	1.51	1.63	1.90	2.21	2.58	2.79
	5	Calc. Thick.	*1.50	*1.60	1.89	2.01	2.28	2.56	2.83
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.51	1.63	1.76	2.05	2.21	2.58	2.79
	8	Calc. Thick.	1.69	1.83	2.00	2.18	2.42	2.64	2.91
		Use Thickness Class.	4	6	7	8	9	10	12
		Use Thickness.	1.63	1.90	2.05	2.21	2.39	2.58	3.01
	12	Calc. Thick.	1.93	2.05	2.19	2.36	2.56	2.78	3.03
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	1.90	2.05	2.21	2.39	2.58	2.79	3.01
	16	Calc. Thick.	2.10	2.22	2.36	2.50	2.68	2.88	3.13
		Use Thickness Class.	7	8	9	10	10	11	13
		Use Thickness.	2.05	2.21	2.39	2.58	2.58	2.79	3.25
60	2½	Calc. Thick.	*1.50	*1.63	*1.78	2.06	2.38	2.73	3.08
		Use Thickness Class.	2	3	4	6	8	10	11
		Use Thickness.	1.50	1.62	1.75	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.55	*1.68	1.84	2.11	2.45	2.77	3.10
		Use Thickness Class.	2	3	5	6	8	10	11
		Use Thickness.	1.50	1.62	1.89	2.04	2.38	2.78	3.00
	5	Calc. Thick.	*1.64	1.79	1.98	2.20	2.53	2.80	3.13
		Use Thickness Class.	3	4	6	7	9	10	12
		Use Thickness.	1.62	1.75	2.04	2.20	2.57	2.78	3.24
	8	Calc. Thick.	1.85	2.00	2.18	2.38	2.63	2.88	3.21
		Use Thickness Class.	5	6	7	8	9	10	12
		Use Thickness.	1.89	2.04	2.20	2.38	2.57	2.78	3.24
	12	Calc. Thick.	2.10	2.24	2.41	2.58	2.83	3.05	3.33
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	2.04	2.20	2.38	2.57	2.78	3.00	3.24
	16	Calc. Thick.	2.39	2.43	2.58	2.75	2.94	3.18	3.41
		Use Thickness Class.	8	8	9	10	11	12	13
		Use Thickness.	2.38	2.38	2.57	2.78	3.00	3.24	3.50

TABLE 2A.2*

Schedule of Barrel Thickness—Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	3½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	5	Calc. Thick.	.25	.26	.26	.27	.29	.31	.32
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	8	Calc. Thick.	.26	.27	.28	.29	.30	.32	.33
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	12	Calc. Thick.	.29	.30	.30	.31	.32	.33	.34
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	16	Calc. Thick.	.31	.31	.32	.33	.34	.35	.36
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
4	2½	Calc. Thick.	*.26	*.27	*.28	.30	.32	.34	.36
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	3½	Calc. Thick.	.26	.27	.29	.31	.32	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	5	Calc. Thick.	.26	.27	.29	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	8	Calc. Thick.	.30	.31	.32	.33	.35	.37	.38
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	12	Calc. Thick.	.32	.33	.35	.36	.37	.39	.40
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	16	Calc. Thick.	.35	.36	.37	.38	.39	.41	.42
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.40	.40	.40	.40	.40	.40	.43
6	2½	Calc. Thick.	.32	.33	.35	.38	.41	.44	.47
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.43	.43	.43	.43	.43	.43	.46
	3½	Calc. Thick.	.32	.33	.35	.38	.41	.44	.48
		Use Thickness Class.	1	1	1	1	1	1	3
		Use Thickness.	.43	.43	.43	.43	.43	.43	.50
	5	Calc. Thick.	.33	.35	.37	.40	.42	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	8	Calc. Thick.	.37	.38	.40	.42	.45	.47	.50
		Use Thickness Class.	1	1	1	1	2	2	3
		Use Thickness.	.43	.43	.43	.43	.46	.46	.50
	12	Calc. Thick.	.41	.42	.44	.46	.48	.50	.52
		Use Thickness Class.	1	1	1	2	3	3	4
		Use Thickness.	.43	.43	.43	.46	.50	.50	.54
	16	Calc. Thick.	.44	.46	.47	.49	.51	.53	.55
		Use Thickness Class.	1	2	2	3	3	4	4
		Use Thickness.	.43	.46	.46	.50	.50	.54	.54

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.2 (*cont'd*)

Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
8	2½	Calc. Thick.	*.37	.38	.41	.45	.49	.53	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	3½	Calc. Thick.	*.37	*.38	.42	.46	.50	.54	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	5	Calc. Thick.	.39	.41	.44	.47	.51	.55	.59
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	8	Calc. Thick.	.44	.46	.48	.51	.54	.57	.61
		Use Thickness Class.	1	1	2	2	3	4	5
		Use Thickness.	.46	.46	.50	.50	.54	.58	.63
	12	Calc. Thick.	.49	.50	.52	.55	.58	.61	.64
		Use Thickness Class.	2	2	3	3	4	5	5
		Use Thickness.	.50	.50	.54	.54	.58	.63	.63
	16	Calc. Thick	.52	.54	.56	.58	.60	.63	.66
		Use Thickness Class.	3	3	4	4	4	5	6
		Use Thickness.	.54	.54	.58	.58	.58	.63	.68
10	2½	Calc. Thick.	*.43	*.45	*.48	.53	.59	.64	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	3½	Calc. Thick.	*.42	*.44	.49	.54	.59	.65	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	5	Calc. Thick.	.45	.48	.52	.56	.61	.66	.71
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.50	.50	.54	.58	.63	.68	.73
	8	Calc. Thick.	.51	.53	.57	.60	.64	.68	.73
		Use Thickness Class.	1	2	3	3	4	5	6
		Use Thickness.	.50	.54	.58	.58	.63	.68	.73
	12	Calc. Thick.	.57	.59	.62	.65	.68	.72	.75
		Use Thickness Class.	3	3	4	4	5	6	6
		Use Thickness.	.58	.58	.63	.63	.68	.73	.73
	16	Calc. Thick.	.59	.62	.64	.67	.70	.74	.78
		Use Thickness Class.	3	4	4	5	5	6	7
		Use Thickness.	.58	.63	.63	.68	.68	.73	.79
12	2½	Calc. Thick.	*.49	*.51	.54	.59	.66	.72	.79
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	3½	Calc. Thick.	*.47	*.49	.54	.60	.67	.73	.80
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	5	Calc. Thick.	.50	.53	.58	.62	.68	.74	.81
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.54	.54	.58	.63	.68	.73	.79
	8	Calc. Thick.	.57	.60	.63	.68	.72	.77	.83
		Use Thickness Class.	2	2	3	4	5	6	7
		Use Thickness.	.58	.58	.63	.68	.73	.79	.85
	12	Calc. Thick.	.62	.65	.69	.72	.76	.81	.86
		Use Thickness Class.	3	3	4	5	6	6	7
		Use Thickness.	.63	.63	.68	.73	.79	.79	.85
	16	Calc. Thick.	.65	.68	.71	.75	.79	.83	.87
		Use Thickness Class.	3	4	5	5	6	7	7
		Use Thickness.	.63	.68	.73	.73	.79	.85	.85

TABLE 2A.2 (*cont'd*)

Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
14	2½	Calc. Thick.	*.52	*.54	.59	.66	.74	.82	.89
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.54	.54	.58	.68	.73	.85	.92
	3½	Calc. Thick.	*.51	.55	.61	.67	.75	.82	.90
		Use Thickness Class.	1	1	3	4	5	7	8
		Use Thickness.	.54	.54	.63	.68	.73	.85	.92
	5	Thick.	.54	.59	.64	.70	.77	.83	.91
		Use Thickness Class.	1	2	3	4	6	7	8
		Use Thickness.	.54	.58	.63	.68	.79	.85	.92
	8	Calc. Thick.	.63	.66	.71	.76	.81	.87	.93
		Use Thickness Class.	3	4	5	6	6	7	8
		Use Thickness.	.63	.68	.73	.79	.79	.85	.92
	12	Calc. Thick.	.68	.71	.75	.80	.85	.90	.96
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.68	.73	.73	.79	.85	.92	.99
	16	Calc. Thick.	.71	.75	.78	.82	.87	.93	.98
		Use Thickness Class.	5	5	6	7	7	8	9
		Use Thickness.	.73	.73	.79	.85	.85	.92	.99
16	2½	Calc. Thick.	*.56	*.58	.63	.72	.80	.89	.98
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.58	.58	.63	.73	.79	.92	.99
	3½	Calc. Thick.	*.55	.59	.66	.73	.81	.90	.98
		Use Thickness Class.	1	1	3	4	5	7	8
		Use Thickness.	.58	.58	.68	.73	.79	.92	.99
	5	Calc. Thick.	.58	.63	.69	.76	.84	.91	1.00
		Use Thickness Class.	1	2	3	5	6	7	8
		Use Thickness.	.58	.63	.68	.79	.85	.92	.99
	8	Calc. Thick.	.67	.71	.76	.81	.88	.95	1.02
		Use Thickness Class.	3	4	5	5	6	7	8
		Use Thickness.	.68	.73	.79	.79	.85	.92	.99
	12	Calc. Thick.	.73	.77	.81	.86	.92	.98	1.05
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.73	.79	.79	.85	.92	.99	1.07
	16	Calc. Thick.	.77	.81	.85	.89	.95	1.00	1.07
		Use Thickness Class.	5	5	6	7	7	8	9
		Use Thickness.	.79	.79	.85	.92	.92	.99	1.07
18	2½	Calc. Thick.	*.59	*.63	.69	.78	.88	.98	1.08
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.63	.63	.68	.79	.85	.99	1.07
	3½	Calc. Thick.	*.59	.64	.72	.80	.89	.99	1.08
		Use Thickness Class.	1	1	3	4	6	7	8
		Use Thickness.	.63	.63	.73	.79	.92	.99	1.07
	5	Calc. Thick.	.63	.69	.75	.83	.92	1.01	1.10
		Use Thickness Class.	1	2	3	5	6	7	8
		Use Thickness.	.63	.68	.73	.85	.92	.99	1.07
	8	Calc. Thick.	.72	.77	.82	.88	.96	1.03	1.12
		Use Thickness Class.	3	4	5	5	7	8	9
		Use Thickness.	.73	.79	.85	.85	.99	1.07	1.16
	12	Calc. Thick.	.78	.84	.88	.95	1.00	1.08	1.16
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.79	.85	.85	.92	.99	1.07	1.16
	16	Calc. Thick.	.83	.87	.91	.97	1.03	1.10	1.17
		Use Thickness Class.	5	5	6	7	8	8	9
		Use Thickness.	.85	.85	.92	.99	1.07	1.07	1.16

TABLE 2A.2 (*cont'd*)

Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
20	2½	Calc. Thick.	*.63	*.67	.72	.83	.94	1.05	1.16
		Use Thickness Class.	1	1	2	4	6	7	8
		Use Thickness.	.66	.66	.71	.83	.97	1.05	1.13
	3½	Calc. Thick.	*.62	.67	.76	.85	.95	1.06	1.17
		Use Thickness Class.	1	1	3	4	6	7	8
		Use Thickness.	.66	.66	.77	.83	.97	1.05	1.13
	5	Calc. Thick.	.66	.73	.80	.89	.98	1.08	1.18
		Use Thickness Class.	1	2	4	5	6	7	9
		Use Thickness.	.66	.71	.83	.90	.97	1.05	1.22
	8	Calc. Thick.	.76	.81	.87	.94	1.02	1.11	1.21
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.77	.83	.90	.97	1.05	1.13	1.22
	12	Calc. Thick.	.83	.88	.93	.99	1.07	1.15	1.24
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.83	.90	90	.97	1.05	1.13	1.22
	16	Calc. Thick.	.87	.92	.97	1.04	1.10	1.18	1.26
		Use Thickness Class.	5	5	6	7	8	9	9
		Use Thickness.	.90	.90	.97	1.05	1.13	1.22	1.22
24	2½	Calc. Thick.	*.69	*.75	.82	.95	1.08	1.21	1.34
		Use Thickness Class.	1	1	2	4	6	7	9
		Use Thickness.	.74	.74	.80	.93	1.08	1.17	1.36
	3½	Calc. Thick.	*.69	.75	.85	.97	1.09	1.23	1.36
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.74	.74	.86	1.00	1.08	1.26	1.36
	5	Calc. Thick.	.75	.82	.91	1.01	1.12	1.24	1.36
		Use Thickness Class.	1	2	4	5	6	8	9
		Use Thickness.	.74	.80	.93	1.00	1.08	1.26	1.36
	8	Calc. Thick.	.83	.91	.98	1.07	1.17	1.28	1.39
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.86	.93	1.00	1.08	1.17	1.26	1.36
	12	Calc. Thick.	.91	.98	1.05	1.13	1.21	1.32	1.43
		Use Thickness Class.	4	5	6	7	7	9	10
		Use Thickness.	.93	1.00	1.08	1.17	1.17	1.36	1.47
	16	Calc. Thick.	.98	1.04	1.10	1.18	1.26	1.36	1.46
		Use Thickness Class.	5	6	6	7	8	9	10
		Use Thickness.	1.00	1.08	1.08	1.17	1.26	1.36	1.47
30	2½	Calc. Thick.	*.81	*.87	.99	1.15	1.31	1.48	1.64
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.87	.87	1.02	1.19	1.29	1.50	1.62
	3½	Calc. Thick.	*.81	.88	1.02	1.17	1.32	1.49	1.65
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.87	.87	1.02	1.19	1.29	1.50	1.62
	5	Calc. Thick.	.87	.96	1.08	1.21	1.35	1.51	1.66
		Use Thickness Class.	1	2	4	5	7	8	9
		Use Thickness.	.87	.94	1.10	1.19	1.39	1.50	1.62
	8	Calc. Thick.	.98	1.06	1.16	1.27	1.40	1.55	1.69
		Use Thickness Class.	3	4	5	6	7	8	10
		Use Thickness.	1.02	1.10	1.19	1.29	1.39	1.50	1.75
	12	Calc. Thick.	1.09	1.16	1.25	1.35	1.46	1.60	1.73
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	1.10	1.19	1.29	1.39	1.50	1.62	1.75
	16	Calc. Thick.	1.16	1.23	1.30	1.40	1.51	1.64	1.76
		Use Thickness Class.	5	5	6	7	8	9	10
		Use Thickness.	1.19	1.19	1.29	1.39	1.50	1.62	1.75

TABLE 2A.2 (*cont'd*)

Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
36	2½	Calc. Thick.	*.91	*.98	1.13	1.31	1.52	1.72	1.93
		Use Thickness Class.	1	1	3	5	7	8	10
		Use Thickness.	.97	.97	1.13	1.32	1.54	1.66	1.93
	3½	Calc. Thick.	*.91	.99	1.15	1.34	1.52	1.73	1.93
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	.97	.97	1.13	1.32	1.54	1.79	1.93
	5	Calc. Thick.	.98	1.09	1.23	1.38	1.54	1.75	1.94
		Use Thickness Class.	1	2	4	6	7	9	10
		Use Thickness.	.97	1.05	1.22	1.43	1.54	1.79	1.93
	8	Calc. Thick.	1.10	1.20	1.32	1.45	1.62	1.78	1.98
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.13	1.22	1.32	1.43	1.66	1.79	1.93
	12	Calc. Thick.	1.22	1.31	1.42	1.54	1.68	1.84	2.03
		Use Thickness Class.	4	5	6	7	8	9	11
		Use Thickness.	1.22	1.32	1.43	1.54	1.66	1.79	2.08
	16	Calc. Thick.	1.30	1.39	1.49	1.61	1.73	1.88	2.05
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.32	1.43	1.54	1.66	1.79	1.93	2.08
42	2½	Calc. Thick.	*1.00	*1.09	1.26	1.48	1.71	1.94	2.18
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	1.07	1.07	1.25	1.46	1.71	2.00	2.16
	3½	Calc. Thick.	*1.01	1.10	1.29	1.50	1.73	1.97	2.21
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	1.07	1.07	1.25	1.46	1.71	2.00	2.16
	5	Calc. Thick.	1.07	1.21	1.36	1.55	1.76	1.97	2.23
		Use Thickness Class.	1	3	4	6	7	9	10
		Use Thickness.	1.07	1.25	1.35	1.58	1.71	2.00	2.16
	8	Calc. Thick.	1.20	1.33	1.47	1.63	1.82	2.02	2.25
		Use Thickness Class.	3	4	5	6	8	9	11
		Use Thickness.	1.25	1.35	1.46	1.58	1.85	2.00	2.33
	12	Calc. Thick.	1.35	1.46	1.58	1.73	1.90	2.08	2.29
		Use Thickness Class.	4	5	6	7	8	10	11
		Use Thickness.	1.35	1.46	1.58	1.71	1.85	2.16	2.33
	16	Calc. Thick.	1.45	1.54	1.67	1.80	1.97	2.16	2.34
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.46	1.58	1.71	1.85	2.00	2.16	2.33
48	2½	Calc. Thick.	*1.08	*1.20	1.42	1.68	1.93	2.21	2.48
		Use Thickness Class.	1	1	3	6	7	9	11
		Use Thickness.	1.18	1.18	1.37	1.73	1.87	2.18	2.54
	3½	Calc. Thick.	*1.10	1.23	1.45	1.70	1.95	2.22	2.49
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.18	1.27	1.48	1.73	2.02	2.18	2.54
	5	Calc. Thick.	1.18	1.33	1.53	1.74	1.98	2.23	2.55
		Use Thickness Class.	1	3	4	6	8	9	11
		Use Thickness.	1.18	1.37	1.48	1.73	2.02	2.18	2.54
	8	Calc. Thick.	1.34	1.47	1.64	1.83	2.04	2.31	2.55
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.37	1.48	1.60	1.87	2.02	2.35	2.54
	12	Calc. Thick.	1.50	1.63	1.77	1.94	2.13	2.36	2.59
		Use Thickness Class.	4	5	6	7	9	10	11
		Use Thickness.	1.48	1.60	1.73	1.87	2.18	2.35	2.54
	16	Calc. Thick.	1.62	1.74	1.87	2.03	2.23	2.42	2.64
		Use Thickness Class.	5	6	7	8	9	10	12
		Use Thickness.	1.60	1.73	1.87	2.02	2.18	2.35	2.74

TABLE 2A.2 (*cont'd*)

Field Condition B

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
54	2½	Calc. Thick.	*1.19	*1.31	1.57	1.88	2.16	2.48	2.78
		Use Thickness Class.	1	1	4	6	8	9	11
		Use Thickness.	1.30	1.30	1.63	1.90	2.21	2.39	2.79
	3½	Cal. Thick.	*1.22	1.36	1.60	1.89	2.18	2.48	2.78
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness..	1.30	1.40	1.63	1.90	2.21	2.39	2.79
	5	Calc. Thick.	1.29	1.48	1.68	1.96	2.22	2.52	2.80
		Use Thickness Class.	1	3	4	6	8	10	11
		Use Thickness.	1.30	1.51	1.63	1.90	2.21	2.58	2.79
	8	Calc. Thick.	1.46	1.62	1.80	2.03	2.29	2.55	2.83
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.51	1.63	1.76	2.05	2.21	2.58	2.79
	12	Calc. Thick.	1.63	1.78	1.95	2.15	2.39	2.63	2.89
		Use Thickness Class.	4	5	6	8	9	10	11
		Use Thickness.	1.63	1.76	1.90	2.21	2.39	2.58	2.79
	16	Calc. Thick.	1.77	1.92	2.06	2.28	2.46	2.68	2.95
		Use Thickness Class.	5	6	7	8	9	10	12
		Use Thickness.	1.76	1.90	2.05	2.21	2.39	2.58	3.01
60	2½	Calc. Thick.	*1.28	1.42	1.73	2.05	2.38	2.73	3.08
		Use Thickness Class.	1	1	4	6	8	10	11
		Use Thickness.	1.39	1.39	1.75	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.32	1.47	1.78	2.07	2.39	2.73	3.08
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.39	1.50	1.75	2.04	2.38	2.78	3.00
	5	Calc. Thick.	1.40	1.59	1.84	2.12	2.43	2.75	3.08
		Use Thickness Class.	1	3	5	7	8	10	11
		Use Thickness.	1.39	1.62	1.89	2.20	2.38	2.78	3.00
	8	Calc. Thick.	1.59	1.77	1.98	2.22	2.49	2.79	3.12
		Use Thickness Class.	3	4	6	7	9	10	12
		Use Thickness.	1.62	1.75	2.04	2.20	2.57	2.78	3.24
	12	Calc. Thick.	1.80	1.95	2.13	2.36	2.60	2.87	3.18
		Use Thickness Class.	4	5	7	8	9	10	12
		Use Thickness.	1.75	1.89	2.20	2.38	2.57	2.78	3.24
	16	Calc. Thick.	1.93	2.08	2.26	2.46	2.68	2.95	3.26
		Use Thickness Class.	5	6	7	8	10	11	12
		Use Thickness.	1.89	2.04	2.20	2.38	2.78	3.00	3.24

TABLE 2A.3*

Schedule of Barrel Thicknesses—Field Condition C

Blocks Having Average Spacing of 6 feet

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.36	*.36	*.37	*.37	*.38	*.39	*.39
		Use Thickness Class.	1	1	1	1	1	2	2
		Use Thickness.	.37	.37	.37	.37	.37	.40	.40
	3½	Calc. Thick.	*.36	*.36	*.37	*.37	*.38	*.38	*.39
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.37	.37	.37	.37	.37	.37	.40
	5	Calc. Thick.	*.38	*.38	*.39	*.39	*.40	*.40	*.41
		Use Thickness Class.	1	1	2	2	2	2	2
		Use Thickness.	.37	.37	.40	.40	.40	.40	.40
	8	Calc. Thick.	.43	.43	.44	.44	.45	.46	.47
		Use Thickness Class.	3	3	3	3	4	4	4
		Use Thickness.	.43	.43	.43	.43	.46	.46	.46
	12	Calc. Thick.	See page 21 for thickness classes required.					.52	.52
		Std. Class No.						6	6
		Std. Class Thick.						.54	.54
	16	Calc. Thick.	See page 21 for thickness classes required.						
		Std. Class No.							
		Std. Class Thick.							
4	2½	Calc. Thick.	*.40	*.41	*.41	*.42	*.43	*.44	*.45
		Use Thickness Class.	1	1	1	2	2	2	3
		Use Thickness.	.40	.40	.40	.43	.43	.43	.46
	3½	Calc. Thick.	*.40	*.40	*.41	*.42	*.43	*.44	*.45
		Use Thickness Class.	1	1	1	2	2	2	3
		Use Thickness.	.40	.40	.40	.43	.43	.43	.46
	5	Calc. Thick.	*.42	*.43	*.44	*.44	*.45	*.46	*.47
		Use Thickness Class.	2	2	2	2	3	3	3
		Use Thickness.	.43	.43	.43	.43	.46	.46	.46
	8	Calc. Thick.	.48	.49	.50	.50	.51	.52	.53
		Use Thickness Class.	4	4	4	4	4	5	5
		Use Thickness.	.50	.50	.50	.50	.50	.54	.54
	12	Calc. Thick.	.56	.56	.57	.58	.59	.60	.60
		Use Thickness Class.	6	6	6	6	6	6	6
		Use Thickness.	.58	.58	.58	.58	.58	.58	.58
	16	Calc. Thick.	.62	.63	.64	.64	.65	.66	.67
		Use Thickness Class.	7	7	7	7	7	8	8
		Use Thickness.	.63	.63	.63	.63	.63	.68	.68

All thicknesses given above for 3-inch and 4-inch pipe are safe for the most favorable block spacing, viz. 30 inches from each end of 12-foot length of pipe or, if longer lengths are used, spacing which does not give greater beam moments, and which averages not over 6 feet. In many cases thicknesses given for 3-inch and 4-inch pipe are not safe for less favorable block spacings. For thicknesses required with less favorable block spacings with 12-foot lengths of pipe, see page 21.

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.3 (*cont'd*)

Schedule of Barrel Thicknesses—Field Condition C

Blocks Having Average Spacing of 6 feet

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
6	2½	Calc. Thick.	*.46	*.47	*.48	*.50	*.51	*.52	*.54
		Use Thickness Class.	2	2	3	3	3	4	4
		Use Thickness.	.46	.46	.50	.50	.50	.54	.54
	3½	Calc. Thick.	*.46	*.47	*.48	*.49	*.51	*.52	*.54
		Use Thickness Class.	2	2	3	3	3	4	4
		Use Thickness.	.46	.46	.50	.50	.50	.54	.54
	5	Calc. Thick.	*.49	*.50	*.51	*.52	*.53	*.55	.57
		Use Thickness Class.	3	3	3	4	4	4	5
		Use Thickness.	.50	.50	.50	.54	.54	.54	.58
	8	Calc. Thick.	.56	.57	.58	.60	.62	.63	.64
		Use Thickness Class.	5	5	5	5	6	6	6
		Use Thickness.	.58	.58	.58	.58	.63	.63	.63
	12	Calc. Thick.	.65	.66	.67	.68	.70	.71	.73
		Use Thickness Class.	y6	7	7	7	7	8	8
		Use Thickness.	.63	.68	.68	.68	.68	.73	.73
	16	Calc. Thick.	.73	.74	.75	.76	.77	.79	.80
		Use Thickness Class.	y8	y8	y8	y9	y9	y9	y9
		Use Thickness.	.73	.73	.73	.79	.79	.79	.79
8	2½	Calc. Thick.	*.52	*.53	*.54	*.56	*.58	*.60	*.62
		Use Thickness Class.	3	3	3	4	4	4	5
		Use Thickness.	.54	.54	.54	.58	.58	.58	.63
	3½	Calc. Thick.	*.51	*.52	*.54	*.56	*.58	*.61	*.63
		Use Thickness Class.	2	3	3	4	4	5	5
		Use Thickness.	.50	.54	.54	.58	.58	.63	.63
	5	Calc. Thick.	*.54	*.55	*.57	.59	.61	.64	.67
		Use Thickness Class.	3	3	4	4	5	5	6
		Use Thickness.	.54	.54	.58	.58	.63	.63	.68
	8	Calc. Thick.	.62	.64	.66	.68	.69	.72	.74
		Use Thickness Class.	5	5	6	6	6	7	7
		Use Thickness.	.63	.63	.68	.68	.68	.73	.73
	12	Calc. Thick.	.73	.74	.76	.78	.79	.82	.84
		Use Thickness Class.	7	7	8	8	8	9	9
		Use Thickness.	.73	.73	.79	.79	.79	.85	.85
	16	Calc. Thick.	.79	.81	.82	.84	.86	.88	.90
		Use Thickness Class.	8	8	9	9	9	9	10
		Use Thickness.	.79	.79	.85	.85	.85	.85	.92

Thicknesses of 6-inch pipe marked y are not safe for all block spacings though safe for the most favorable block spacing (see note page 19). For thicknesses required with 12-foot lengths in cases marked y see page 19.

TABLE 2A.3 (*cont'd*)
SUPPLEMENTARY THICKNESS TABLE

For Small Pipe Acting as Beams Spanning between Blocks in Field Condition C

Modulus of Rupture of Iron in Pipe as Beam—26,000 lb. per sq. in.

Explanatory Note. This table contains thickness classes computed as required for pipe as beams spanning between blocks, assuming no support from the untamped backfill which will run under the pipe. Net thicknesses, i.e., thicknesses with combined foundry tolerance and corrosion allowances of 0.15 inch deducted from standard thickness, are used in computing beam strengths. Required thickness classes are given for both favorable and unfavorable block spacings. Thickness classes here given should be used where they are larger than those shown in the previous sheets in which the pipe were computed as rings subjected to water pressure and fill loads, disregarding beam.

DISTANCES OF BLOCKS FROM ENDS OF 12-FOOT LENGTHS OF PIPE, INCHES	NOMINAL DIAMETER OF PIPE, INCHES	DEPTH OF COVER—FEET					
		2½	3½	5	8	12	16
21	3	6**	6**	9**	x	x	x
	4	2†	2†	4**	10**	x	x
	6	1	1	1	3	7†	x
	8	1	1	1	1	2	4
30 (most favorable)	3	1	1	1	2	6†	x
	4	1	1	1	1	3	7
	6	1	1	1	1	1	1
	8	1	1	1	1	1	1
36	3	1	1	2†	6	x	x
	4	1	1	1	3	8	x
	6	1	1	1	1	1	4
	8	1	1	1	1	1	1
12 & 30	3	6**	6**	9**	x	x	x
	4	1	1	4**	9**	x	x
	6	1	1	1	2	7†	x
	8	1	1	1	1	2	4

** Heavier than required for pipe as ring with same cover and all water pressures up to and including 350 lb.

† Heavier than required for pipe computed as a ring with the same cover and one or more of the several water pressures.

x No class heavy enough.

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
10	2½	Calc. Thick.	*.57	*.59	*.61	*.63	*.65	*.68	*.71
		Use Thickness Class.	3	3	4	4	4	5	6
		Use Thickness.	.58	.58	.63	.63	.63	.68	.73
	3½	Calc. Thick.	*.56	*.58	*.60	*.62	*.65	*.69	*.73
		Use Thickness Class.	3	3	3	4	4	5	6
		Use Thickness.	.58	.58	.58	.63	.63	.68	.73
	5	Calc. Thick.	*.59	*.61	.64	.67	.70	.74	.78
		Use Thickness Class.	3	4	4	5	5	6	7
		Use Thickness.	.58	.63	.63	.68	.68	.73	.79
	8	Calc. Thick.	.69	.71	.73	.76	.79	.81	.84
		Use Thickness Class.	5	6	6	7	7	7	8
		Use Thickness.	.68	.73	.73	.79	.79	.79	.85
	12	Calc. Thick.	.80	.81	.84	.86	.88	.91	.94
		Use Thickness Class.	7	7	8	8	8	9	9
		Use Thickness.	.79	.79	.85	.85	.85	.92	.92
	16	Calc. Thick.	.84	.86	.88	.90	.93	.95	.98
		Use Thickness Class.	8	8	8	9	9	9	10
		Use Thickness.	.85	.85	.85	.92	.92	.92	.99

TABLE 2A.3 (*cont'd*)

Field Condition C

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
12	2½	Calc. Thick.	*.61	*.63	*.65	*.68	*.71	.75	.81
		Use Thickness Class.	3	3	3	4	5	5	6
		Use Thickness.	.63	.63	.63	.68	.73	.73	.79
	3½	Calc. Thick.	*.60	*.62	*.64	*.67	.71	.77	.82
		Use Thickness Class.	2	3	3	4	5	6	7
		Use Thickness.	.58	.63	.63	.68	.73	.79	.85
	5	Calc. Thick.	*.63	*.65	.69	.72	.76	.81	.86
		Use Thickness Class.	3	3	4	5	6	6	7
		Use Thickness.	.63	.63	.68	.73	.79	.79	.85
	8	Calc. Thick	.74	.76	.79	.83	.86	.89	.94
		Use Thickness Class.	5	6	6	7	7	8	8
		Use Thickness.	.73	.79	.79	.85	.85	.92	.92
	12	Calc. Thick.	.83	.84	.87	.91	.94	.97	1.01
		Use Thickness Class.	7	7	7	8	8	9	9
		Use Thickness.	.85	.85	.85	.92	.92	.99	.99
	16	Calc. Thick.	.87	.90	.92	.95	.98	1.01	1.05
		Use Thickness Class.	7	8	8	8	9	9	10
		Use Thickness.	.85	.92	.92	.92	.99	.99	1.07
14	2½	Calc. Thick.	*.65	*.67	*.70	*.73	*.77	.83	.91
		Use Thickness Class.	3	4	4	5	6	7	8
		Use Thickness.	.63	.68	.68	.73	.79	.85	.92
	3½	Calc. Thick.	*.64	*.67	*.70	.73	.79	.85	.92
		Use Thickness Class.	3	4	4	5	6	7	8
		Use Thickness.	.63	.68	.68	.73	.79	.85	.92
	5	Calc. Thick.	*.68	.71	.75	.79	.85	.90	.96
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.68	.73	.73	.79	.85	.92	.99
	8	Calc. Thick.	.80	.83	.86	.90	.94	.99	1.04
		Use Thickness Class.	6	7	7	8	8	9	10
		Use Thickness.	.79	.85	.85	.92	.92	.99	1.07
	12	Calc. Thick	.87	.90	.93	.97	1.01	1.05	1.10
		Use Thickness Class.	7	8	8	9	9	10	10
		Use Thickness.	.85	.92	.92	.99	.99	1.07	1.07
	16	Calc. Thick	.92	.95	.98	1.02	1.05	1.09	1.14
		Use Thickness Class.	8	8	9	9	10	10	11
		Use Thickness.	.92	.92	.99	.99	1.07	1.07	1.16
16	2½	Calc. Thick.	*.68	*.71	*.74	*.78	*.83	.90	1.00
		Use Thickness Class.	3	4	4	5	6	7	8
		Use Thickness.	.68	.73	.73	.79	.85	.92	.99
	3½	Calc. Thick.	*.68	*.71	*.75	.78	.85	.92	1.01
		Use Thickness Class.	3	4	4	5	6	7	8
		Use Thickness.	.68	.73	.73	.79	.85	.92	.99
	5	Calc. Thick.	*.72	*.75	.79	.85	.91	.97	1.04
		Use Thickness Class.	4	4	5	6	7	8	9
		Use Thickness.	.73	.73	.79	.85	.92	.99	1.07
	8	Calc. Thick.	.83	.87	.91	.95	1.00	1.06	1.12
		Use Thickness Class.	6	6	7	7	8	9	10
		Use Thickness.	.85	.85	.92	.92	.99	1.07	1.16
	12	Calc. Thick.	.92	.95	.99	1.03	1.07	1.12	1.18
		Use Thickness Class.	7	7	8	9	9	10	10
		Use Thickness.	.92	.92	.99	1.07	1.07	1.16	1.16
	16	Calc. Thick.	.97	1.00	1.04	1.08	1.12	1.17	1.22
		Use Thickness Class.	8	8	9	9	10	10	11
		Use Thickness.	.99	.99	1.07	1.07	1.16	1.16	1.25

TABLE 2A.3 (*cont'd*)

Field Condition C

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
18	2½	Calc. Thick.	*.73	*.76	*.80	*.84	.90	.99	1.09
		Use {Thickness Class.	3	4	4	5	6	7	8
		Use {Thickness.	.73	.79	.79	.85	.92	.99	1.07
	3½	Calc. Thick.	*.72	*.75	*.79	.85	.93	1.02	1.11
		Use {Thickness Class.	3	3	4	5	6	7	8
		Use {Thickness.	.73	.73	.79	.85	.92	.99	1.07
	5	Calc. Thick.	*.77	*.80	.86	.92	.99	1.06	1.14
		Use {Thickness Class.	4	4	5	6	7	8	9
		Use {Thickness.	.79	.79	.85	.92	.99	1.07	1.16
	8	Calc. Thick.	.88	.92	.97	1.02	1.08	1.14	1.21
		Use {Thickness Class.	5	6	7	7	8	9	10
		Use {Thickness.	.85	.92	.99	.99	1.07	1.16	1.25
	12	Calc. Thick.	.96	1.01	1.06	1.10	1.15	1.21	1.27
		Use {Thickness Class.	7	7	8	8	9	10	10
		Use {Thickness.	.99	.99	1.07	1.07	1.16	1.25	1.25
	16	Calc. Thick.	1.03	1.07	1.11	1.15	1.20	1.26	1.32
		Use {Thickness Class.	8	8	8	9	9	10	11
		Use {Thickness.	1.07	1.07	1.07	1.16	1.16	1.25	1.35
20	2½	Calc. Thick.	*.77	*.81	*.85	*.90	.96	1.06	1.17
		Use {Thickness Class.	3	4	4	5	6	7	8
		Use {Thickness.	.77	.83	.83	.90	.97	1.05	1.13
	3½	Calc. Thick.	*.77	*.81	*.85	.90	.99	1.08	1.19
		Use {Thickness Class.	3	4	4	5	6	7	9
		Use {Thickness.	.77	.83	.83	.90	.97	1.05	1.22
	5	Calc. Thick.	*.81	*.85	.91	.97	1.06	1.14	1.23
		Use {Thickness Class.	4	4	5	6	7	8	9
		Use {Thickness.	.83	.83	.90	.97	1.05	1.13	1.22
	8	Calc. Thick.	.91	.96	1.02	1.07	1.14	1.21	1.29
		Use {Thickness Class.	5	6	7	7	8	9	10
		Use {Thickness.	.90	.97	1.05	1.05	1.13	1.22	1.32
	12	Calc. Thick.	1.02	1.06	1.11	1.16	1.22	1.29	1.36
		Use {Thickness Class.	7	7	8	8	9	10	10
		Use {Thickness.	1.05	1.05	1.13	1.13	1.22	1.32	1.32
	16	Calc. Thick.	1.09	1.13	1.17	1.22	1.28	1.35	1.41
		Use {Thickness Class.	8	8	8	9	10	10	11
		Use {Thickness.	1.13	1.13	1.13	1.22	1.32	1.32	1.43
24	2½	Calc. Thick.	*.85	*.89	*.94	*1.00	1.10	1.23	1.35
		Use {Thickness Class.	3	3	4	5	6	8	9
		Use {Thickness.	.86	.86	.93	1.00	1.08	1.26	1.36
	3½	Calc. Thick.	*.85	*.89	*.94	1.02	1.13	1.25	1.37
		Use {Thickness Class.	3	3	4	5	7	8	9
		Use {Thickness.	.86	.86	.93	1.00	1.17	1.26	1.36
	5	Calc. Thick.	*.89	*.94	1.02	1.10	1.19	1.30	1.41
		Use {Thickness Class.	3	4	5	6	7	8	9
		Use {Thickness.	.86	.93	1.00	1.08	1.17	1.26	1.36
	8	Calc. Thick.	1.01	1.06	1.12	1.20	1.28	1.37	1.48
		Use {Thickness Class.	5	6	6	7	8	9	10
		Use {Thickness.	1.00	1.08	1.08	1.17	1.26	1.36	1.47
	12	Calc. Thick.	1.13	1.18	1.24	1.30	1.37	1.46	1.55
		Use {Thickness Class.	7	7	8	8	9	10	11
		Use {Thickness.	1.17	1.17	1.26	1.26	1.36	1.47	1.59
	16	Calc. Thick.	1.20	1.26	1.31	1.37	1.44	1.52	1.60
		Use {Thickness Class.	7	8	9	9	10	10	11
		Use {Thickness.	1.17	1.26	1.36	1.36	1.47	1.47	1.59

TABLE 2A.3 (*cont'd*)

Field Condition C

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
30	2½	Calc. Thick.	*.99	*1.05	*1.11	1.19	1.33	1.49	1.65
		Use Thickness Class.	3	3	4	5	6	8	9
		Use Thickness.	1.02	1.02	1.10	1.19	1.29	1.50	1.62
	3½	Calc. Thick.	*.99	*1.04	*1.11	1.21	1.36	1.51	1.67
		Use Thickness Class.	3	3	4	5	7	8	9
		Use Thickness.	1.02	1.02	1.10	1.19	1.39	1.50	1.62
	5	Calc. Thick.	*1.04	*1.13	1.21	1.32	1.45	1.58	1.73
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.02	1.10	1.19	1.29	1.50	1.62	1.75
	8	Calc. Thick.	1.18	1.25	1.35	1.43	1.54	1.66	1.78
		Use Thickness Class.	5	6	7	7	8	9	10
		Use Thickness.	1.19	1.29	1.39	1.39	1.50	1.62	1.75
	12	Calc. Thick.	1.32	1.38	1.46	1.54	1.63	1.74	1.87
		Use Thickness Class.	6	7	8	8	9	10	11
		Use Thickness.	1.29	1.39	1.50	1.50	1.62	1.75	1.89
	16	Calc. Thick.	1.41	1.48	1.55	1.62	1.71	1.81	1.92
		Use Thickness Class.	7	8	8	9	10	10	11
		Use Thickness.	1.39	1.50	1.50	1.62	1.75	1.75	1.89
36	2½	Calc. Thick.	*1.11	*1.18	*1.26	1.36	1.53	1.73	1.93
		Use Thickness Class.	3	4	4	5	7	9	10
		Use Thickness.	1.13	1.22	1.22	1.32	1.54	1.79	1.93
	3½	Calc. Thick.	*1.11	*1.18	*1.26	1.40	1.58	1.74	1.94
		Use Thickness Class.	3	4	4	6	7	9	10
		Use Thickness.	1.13	1.22	1.22	1.43	1.54	1.79	1.93
	5	Calc. Thick.	*1.18	*1.25	1.35	1.44	1.65	1.81	2.01
		Use Thickness Class.	4	4	5	6	8	9	11
		Use Thickness.	1.22	1.22	1.32	1.43	1.66	1.79	2.08
	8	Calc. Thick.	1.31	1.40	1.50	1.62	1.75	1.90	2.08
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.32	1.43	1.54	1.66	1.79	1.93	2.08
	12	Calc. Thick.	1.49	1.56	1.65	1.76	1.88	2.01	2.15
		Use Thickness Class.	7	7	8	9	10	11	11
		Use Thickness.	1.54	1.54	1.66	1.79	1.93	2.08	2.08
	16	Calc. Thick.	1.61	1.68	1.77	1.87	1.98	2.09	2.23
		Use Thickness Class.	8	8	9	10	10	11	12
		Use Thickness.	1.66	1.66	1.79	1.93	1.93	2.08	2.25
42	2½	Calc. Thick.	*1.23	*1.31	*1.40	1.52	1.74	1.96	2.23
		Use Thickness Class.	3	4	4	6	7	9	10
		Use Thickness.	1.25	1.35	1.35	1.58	1.71	2.00	2.16
	3½	Calc. Thick.	*1.25	*1.32	*1.41	1.58	1.78	1.98	2.23
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.25	1.35	1.46	1.58	1.85	2.00	2.16
	5	Calc. Thick.	*1.32	*1.40	1.51	1.66	1.84	2.05	2.28
		Use Thickness Class.	4	4	5	7	8	9	11
		Use Thickness.	1.35	1.35	1.46	1.71	1.85	2.00	2.33
	8	Calc. Thick.	1.47	1.57	1.68	1.81	1.97	2.16	2.36
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.46	1.58	1.71	1.85	2.00	2.16	2.33
	12	Calc. Thick.	1.65	1.74	1.85	1.97	2.11	2.28	2.45
		Use Thickness Class.	7	7	8	9	10	11	12
		Use Thickness.	1.71	1.71	1.85	2.00	2.16	2.33	2.52
	16	Calc. Thick.	1.80	1.88	1.98	2.09	2.23	2.38	2.54
		Use Thickness Class.	8	8	9	10	10	11	12
		Use Thickness.	1.85	1.85	2.00	2.16	2.16	2.33	2.52

TABLE 2A.3 (*cont'd*)

Field Condition C

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
48	2½	Calc. Thick.	*1.34	*1.44	*1.55	1.71	1.96	2.23	2.50
		Use Thickness Class.	3	4	5	6	8	9	11
		Use Thickness.	1.37	1.48	1.60	1.73	2.02	2.18	2.54
	3½	Calc. Thick.	*1.35	*1.45	*1.56	1.76	1.99	2.25	2.52
		Use Thickness Class.	3	4	5	6	8	9	11
		Use Thickness.	1.37	1.48	1.60	1.73	2.02	2.18	2.54
	5	Calc. Thick.	*1.45	*1.55	1.69	1.87	2.08	2.32	2.57
		Use Thickness Class.	4	5	6	7	8	10	11
		Use Thickness.	1.48	1.60	1.73	1.87	2.02	2.35	2.54
	8	Calc. Thick.	1.63	1.74	1.88	2.03	2.22	2.42	2.65
		Use Thickness Class.	5	6	7	8	9	10	12
		Use Thickness.	1.60	1.73	1.87	2.02	2.18	2.35	2.74
	12	Calc. Thick.	1.85	1.95	2.07	2.22	2.38	2.56	2.75
		Use Thickness Class.	7	8	8	9	10	11	12
		Use Thickness.	1.87	2.02	2.02	2.18	2.35	2.54	2.74
	16	Calc. Thick.	2.03	2.13	2.24	2.35	2.50	2.68	2.84
		Use Thickness Class.	8	9	9	10	11	12	12
		Use Thickness.	2.02	2.18	2.18	2.35	2.54	2.74	2.74
54	2½	Calc. Thick.	*1.48	*1.58	*1.72	1.91	2.18	2.48	2.78
		Use Thickness Class.	3	4	5	6	8	9	11
		Use Thickness.	1.51	1.63	1.76	1.90	2.21	2.39	2.79
	3½	Calc. Thick.	*1.52	*1.63	*1.75	1.98	2.23	2.53	2.80
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.51	1.63	1.76	2.05	2.21	2.58	2.79
	5	Calc. Thick.	*1.60	*1.70	1.87	2.08	2.33	2.58	2.85
		Use Thickness Class.	4	5	6	7	9	10	11
		Use Thickness.	1.63	1.76	1.90	2.05	2.39	2.58	2.79
	8	Calc. Thick.	1.79	1.93	2.08	2.26	2.46	2.69	2.95
		Use Thickness Class.	5	6	7	8	9	11	12
		Use Thickness.	1.76	1.90	2.05	2.21	2.39	2.79	3.01
	12	Calc. Thick.	2.03	2.15	2.28	2.45	2.63	2.84	3.08
		Use Thickness Class.	7	8	8	9	10	11	12
		Use Thickness.	2.05	2.21	2.21	2.39	2.58	2.79	3.01
	16	Calc. Thick.	2.23	2.34	2.47	2.61	2.78	2.98	3.19
		Use Thickness Class.	8	9	9	10	11	12	13
		Use Thickness.	2.21	2.39	2.39	2.58	2.79	3.01	3.25
60	2½	Calc. Thick.	*1.58	*1.72	*1.87	2.08	2.43	2.73	3.08
		Use Thickness Class.	3	4	5	6	8	10	11
		Use Thickness.	1.62	1.75	1.89	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.64	*1.78	*1.91	2.16	2.47	2.78	3.09
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.62	1.75	1.89	2.20	2.38	2.78	3.00
	5	Calc. Thick.	*1.73	*1.85	2.04	2.28	2.53	2.83	3.13
		Use Thickness Class.	4	5	6	7	9	10	12
		Use Thickness.	1.75	1.89	2.04	2.20	2.57	2.78	3.24
	8	Calc. Thick.	1.95	2.10	2.27	2.46	2.71	2.95	3.24
		Use Thickness Class.	5	6	7	8	10	11	12
		Use Thickness.	1.89	2.04	2.20	2.38	2.78	3.00	3.24
	12	Calc. Thick.	2.24	2.38	2.52	2.69	2.89	3.14	3.38
		Use Thickness Class.	7	8	9	10	11	12	13
		Use Thickness.	2.20	2.38	2.57	2.78	3.00	3.24	3.50
	16	Calc. Thick.	2.43	2.55	2.70	2.86	3.05	3.28	3.52
		Use Thickness Class.	8	9	10	10	11	12	13
		Use Thickness.	2.38	2.57	2.78	2.78	3.00	3.24	3.50

TABLE 2A.4*

Schedule of Barrel Thicknesses—Field Condition D

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	3½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	5	Calc. Thick.	.25	.26	.26	.27	.29	.31	.32
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	8	Calc. Thick.	.27	.27	.29	.30	.31	.32	.33
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	12	Calc. Thick.	.29	.30	.31	.31	.32	.33	.35
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	16	Calc. Thick.	.31	.32	.32	.33	.34	.35	.36
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
4	2½	Calc. Thick.	*.26	*.27	.29	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	3½	Calc. Thick.	*.27	*.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	5	Calc. Thick.	*.27	.28	.30	.32	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	8	Calc. Thick.	.31	.32	.32	.33	.35	.37	.40
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	12	Calc. Thick.	.32	.33	.35	.36	.37	.39	.40
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	16	Calc. Thick.	.36	.37	.38	.39	.40	.41	.42
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.40	.40	.40	.40	.40	.40	.43
6	2½	Calc. Thick.	*.33	*.34	*.35	.38	.41	.44	.47
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.43	.43	.43	.43	.43	.43	.46
	3½	Calc. Thick.	.32	.33	.35	.38	.41	.44	.47
		Use Thickness Class.	1	1	1	1	1	1	2
		Use Thickness.	.43	.43	.43	.43	.43	.43	.46
	5	Calc. Thick.	.33	.35	.37	.40	.43	.46	.49
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	8	Calc. Thick.	.38	.40	.41	.43	.45	.47	.50
		Use Thickness Class.	1	1	1	1	2	2	3
		Use Thickness.	.43	.43	.43	.43	.46	.46	.50
	12	Calc. Thick.	.42	.43	.45	.47	.48	.50	.53
		Use Thickness Class.	1	1	2	2	3	3	4
		Use Thickness.	.43	.43	.46	.46	.50	.50	.54
	16	Calc. Thick.	.46	.47	.48	.50	.51	.53	.55
		Use Thickness Class.	2	2	3	3	3	4	4
		Use Thickness.	.46	.46	.50	.50	.50	.54	.54

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.4 (*cont'd*)

Field Condition D

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
8	2½	Calc. Thick.	*.40	*.42	*.43	.46	.50	.54	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	3½	Calc. Thick.	*.39	*.41	.44	.48	.51	.55	.59
		Use Thickness Class.	1	1	1	2	2	3	4
		Use Thickness.	.46	.46	.46	.50	.50	.54	.58
	5	Calc. Thick.	.42	.44	.46	.49	.53	.56	.60
		Use Thickness Class.	1	1	1	2	3	4	4
		Use Thickness.	.46	.46	.46	.50	.54	.58	.58
	8	Calc. Thick.	.47	.49	.51	.53	.56	.59	.62
		Use Thickness Class.	1	2	2	3	4	4	5
		Use Thickness.	.46	.50	.50	.54	.58	.58	.63
	12	Calc. Thick.	.52	.54	.56	.58	.61	.63	.66
		Use Thickness Class.	3	3	4	4	5	5	6
		Use Thickness.	.54	.54	.58	.58	.63	.63	.68
	16	Calc. Thick.	.57	.59	.61	.63	.65	.68	.70
		Use Thickness Class.	4	4	5	5	5	6	6
		Use Thickness.	.58	.58	.63	.63	.63	.68	.68
10	2½	Calc. Thick.	*.48	*.49	*.51	*.54	.59	.65	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	3½	Calc. Thick.	*.46	*.47	.51	.55	.60	.65	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	5	Calc. Thick.	*.48	.51	.54	.58	.62	.67	.72
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.50	.50	.54	.58	.63	.68	.73
	8	Calc. Thick.	.55	.57	.60	.63	.67	.71	.75
		Use Thickness Class.	2	3	3	4	5	6	6
		Use Thickness.	.54	.58	.58	.63	.68	.73	.73
	12	Calc. Thick.	.62	.64	.67	.69	.72	.76	.80
		Use Thickness Class.	4	4	5	5	6	7	7
		Use Thickness.	.63	.63	.68	.68	.73	.79	.79
	16	Calc. Thick.	.68	.70	.72	.75	.78	.81	.84
		Use Thickness Class.	5	5	6	6	7	7	8
		Use Thickness.	.68	.68	.73	.73	.79	.79	.85
12	2½	Calc. Thick.	*.53	*.55	*.57	.61	.67	.73	.80
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.54	.54	.58	.63	.68	.73	.79
	3½	Calc. Thick.	*.51	*.53	.57	.62	.67	.73	.80
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.54	.54	.58	.63	.68	.73	.79
	5	Calc. Thick.	*.53	.57	.61	.66	.71	.76	.82
		Use Thickness Class.	1	2	3	4	5	6	7
		Use Thickness.	.54	.58	.63	.68	.73	.79	.85
	8	Calc. Thick.	.61	.64	.67	.71	.75	.80	.85
		Use Thickness Class.	3	3	4	5	5	6	7
		Use Thickness.	.63	.63	.68	.73	.73	.79	.85
	12	Calc. Thick.	.70	.72	.75	.79	.82	.87	.92
		Use Thickness Class.	4	5	5	6	7	7	8
		Use Thickness.	.68	.73	.73	.79	.85	.85	.92
	16	Calc. Thick.	.76	.78	.81	.84	.88	.92	.96
		Use Thickness Class.	6	6	6	7	7	8	9
		Use Thickness.	.79	.79	.79	.85	.85	.92	.99

TABLE 2A.4 (*cont'd*)

Field Condition D

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
14	2½	Calc. Thick.	*.58	*.60	*.63	*.67	.75	.82	.90
		Use Thickness Class.	2	2	3	4	5	7	8
		Use Thickness.	.58	.58	.63	.68	.73	.85	.92
	3½	Calc. Thick.	*.57	*.60	.64	.70	.77	.84	.91
		Use Thickness Class.	2	2	3	4	6	7	8
		Use Thickness.	.58	.58	.63	.68	.79	.85	.92
	5	Calc. Thick.	.60	.64	.68	.73	.79	.86	.92
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.58	.63	.68	.73	.79	.85	.92
	8	Calc. Thick.	.70	.73	.77	.81	.86	.91	.97
		Use Thickness Class.	4	5	6	6	7	8	9
		Use Thickness.	.68	.73	.79	.79	.85	.92	.99
	12	Calc. Thick.	.78	.81	.85	.89	.92	.97	1.03
		Use Thickness Class.	6	6	7	8	8	9	10
		Use Thickness.	.79	.79	.85	.92	.92	.99	1.07
	16	Calc. Thick.	.82	.86	.90	.93	.97	1.01	1.06
		Use Thickness Class.	7	7	8	8	9	9	10
		Use Thickness.	.85	.85	.92	.92	.99	.99	1.07
16	2½	Calc. Thick.	*.62	*.65	*.68	*.73	.81	.90	.99
		Use Thickness Class.	2	2	3	4	5	7	8
		Use Thickness.	.63	.63	.68	.73	.79	.92	.99
	3½	Calc. Thick.	*.62	*.65	*.68	.75	.83	.91	.99
		Use Thickness Class.	2	2	3	4	6	7	8
		Use Thickness.	.63	.63	.68	.73	.85	.92	.99
	5	Calc. Thick.	*.64	.68	.74	.80	.86	.92	1.00
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.63	.68	.73	.79	.85	.92	.99
	8	Calc. Thick.	.75	.79	.83	.88	.93	.99	1.06
		Use Thickness Class.	4	5	6	6	7	8	9
		Use Thickness.	.73	.79	.85	.85	.92	.99	1.07
	12	Calc. Thick.	.84	.87	.91	.95	1.00	1.06	1.12
		Use Thickness Class.	6	6	7	7	8	9	10
		Use Thickness.	.85	.85	.92	.92	.99	1.07	1.16
	16	Calc. Thick.	.88	.91	.95	1.00	1.04	1.10	1.15
		Use Thickness Class.	6	7	7	8	9	9	10
		Use Thickness.	.85	.92	.92	.99	1.07	1.07	1.16
18	2½	Calc. Thick.	*.67	*.70	*.74	*.79	.89	.98	1.08
		Use Thickness Class.	2	2	3	4	6	7	8
		Use Thickness.	.68	.68	.73	.79	.92	.99	1.07
	3½	Calc. Thick.	*.66	*.69	.74	.82	.91	1.00	1.09
		Use Thickness Class.	2	2	3	5	6	7	8
		Use Thickness.	.68	.68	.73	.85	.92	.99	1.07
	5	Calc. Thick.	.70	.74	.80	.87	.95	1.03	1.10
		Use Thickness Class.	2	3	4	5	6	8	8
		Use Thickness.	.68	.73	.79	.85	.92	1.07	1.07
	8	Calc. Thick.	.81	.85	.90	.96	1.02	1.09	1.17
		Use Thickness Class.	4	5	6	7	7	8	9
		Use Thickness.	.79	.85	.92	.99	.99	1.07	1.16
	12	Calc. Thick.	.89	.93	.98	1.03	1.08	1.15	1.22
		Use Thickness Class.	6	6	7	8	8	9	10
		Use Thickness.	.92	.92	.99	1.07	1.07	1.16	1.25
	16	Calc. Thick.	.94	.98	1.03	1.08	1.15	1.20	1.27
		Use Thickness Class.	6	7	8	8	9	9	10
		Use Thickness.	.92	.99	1.07	1.07	1.16	1.16	1.25

TABLE 2A.4 (*cont'd*)

Field Condition D

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
20	2½	Calc. Thick.	*.71	*.75	*.79	*.85	.95	1.05	1.16
		Use Thickness Class.	2	3	3	4	6	7	8
		Use Thickness.	.71	.77	.77	.83	.97	1.05	1.13
	3½	Calc. Thick.	*.71	*.75	*.79	.87	.97	1.07	1.19
		Use Thickness Class.	2	3	3	5	6	7	9
		Use Thickness.	.71	.77	.77	.90	.97	1.05	1.22
	5	Calc. Thick.	*.75	.80	.86	.93	1.02	1.11	1.21
		Use Thickness Class.	3	4	4	5	7	8	9
		Use Thickness.	.77	.83	.83	.90	1.05	1.13	1.22
	8	Calc. Thick.	.85	.90	.96	1.02	1.09	1.17	1.26
		Use Thickness Class.	4	5	6	7	8	8	9
		Use Thickness.	.83	.90	.97	1.05	1.13	1.13	1.22
	12	Calc. Thick.	.94	.99	1.04	1.09	1.15	1.23	1.31
		Use Thickness Class.	6	6	7	8	8	9	10
		Use Thickness.	.97	.97	1.05	1.13	1.13	1.22	1.32
	16	Calc. Thick.	1.00	1.04	1.09	1.14	1.21	1.27	1.35
		Use Thickness Class.	6	7	8	8	9	10	10
		Use Thickness.	.97	1.05	1.13	1.13	1.22	1.32	1.32
24	2½	Calc. Thick.	*.79	*.83	*.88	.96	1.08	1.21	1.35
		Use Thickness Class.	2	3	3	4	6	7	9
		Use Thickness.	.80	.86	.86	.93	1.08	1.17	1.36
	3½	Calc. Thick.	*.78	*.83	*.88	.99	1.11	1.24	1.36
		Use Thickness Class.	2	3	3	5	6	8	9
		Use Thickness.	.80	.86	.86	1.00	1.08	1.26	1.36
	5	Calc. Thick.	*.84	.90	.97	1.06	1.16	1.28	1.39
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.86	.93	1.00	1.08	1.17	1.26	1.36
	8	Calc. Thick.	.92	.99	1.06	1.14	1.22	1.33	1.44
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	.93	1.00	1.08	1.17	1.26	1.36	1.47
	12	Calc. Thick.	1.04	1.10	1.16	1.23	1.31	1.40	1.50
		Use Thickness Class.	6	6	7	8	9	9	10
		Use Thickness.	1.08	1.08	1.17	1.26	1.36	1.36	1.47
	16	Calc. Thick.	1.11	1.16	1.22	1.28	1.36	1.45	1.54
		Use Thickness Class.	6	7	8	8	9	10	11
		Use Thickness.	1.08	1.17	1.26	1.26	1.36	1.47	1.59
30	2½	Calc. Thick.	*.91	*.97	*1.04	1.17	1.32	1.48	1.64
		Use Thickness Class.	2	2	3	5	6	8	9
		Use Thickness.	.94	.94	1.02	1.19	1.29	1.50	1.62
	3½	Calc. Thick.	*.91	*.97	1.06	1.20	1.34	1.50	1.66
		Use Thickness Class.	2	2	4	5	7	8	9
		Use Thickness.	.94	.94	1.10	1.19	1.39	1.50	1.62
	5	Calc. Thick.	*.97	1.05	1.15	1.27	1.39	1.53	1.68
		Use Thickness Class.	2	3	5	6	7	8	9
		Use Thickness.	.94	1.02	1.19	1.29	1.39	1.50	1.62
	8	Calc. Thick.	1.09	1.17	1.26	1.35	1.47	1.60	1.73
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	1.10	1.19	1.29	1.39	1.50	1.62	1.75
	12	Calc. Thick.	1.22	1.29	1.37	1.45	1.56	1.68	1.81
		Use Thickness Class.	5	6	7	8	9	10	10
		Use Thickness.	1.19	1.29	1.39	1.50	1.62	1.62	1.75
	16	Calc. Thick.	1.30	1.37	1.45	1.53	1.63	1.74	1.85
		Use Thickness Class.	6	7	8	8	9	10	11
		Use Thickness.	1.29	1.39	1.50	1.50	1.62	1.75	1.89

TABLE 2A.4 (*cont'd*)

Field Condition D

S = 11,000 lb. per sq. in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
36	2½	Calc. Thick.	*1.01	*1.09	*1.18	1.33	1.53	1.73	1.92
		Use Thickness Class.	2	3	4	5	7	9	10
		Use Thickness.	1.05	1.13	1.22	1.32	1.54	1.79	1.93
	3½	Calc. Thick.	*1.01	*1.09	1.20	1.36	1.54	1.73	1.92
		Use Thickness Class.	2	3	4	5	7	9	10
		Use Thickness.	1.05	1.13	1.22	1.32	1.54	1.79	1.93
	5	Calc. Thick.	*1.08	1.16	1.28	1.43	1.60	1.78	1.98
		Use Thickness Class.	2	3	5	6	8	9	10
		Use Thickness.	1.05	1.13	1.32	1.43	1.66	1.79	1.93
	8	Calc. Thick.	1.23	1.31	1.42	1.54	1.69	1.84	2.03
		Use Thickness Class.	4	5	6	7	8	9	11
		Use Thickness.	1.22	1.32	1.43	1.54	1.66	1.79	2.08
	12	Calc. Thick.	1.37	1.45	1.55	1.66	1.78	1.93	2.09
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.32	1.43	1.54	1.66	1.79	1.93	2.08
	16	Calc. Thick.	1.47	1.55	1.64	1.75	1.87	2.00	2.14
		Use Thickness Class.	6	7	8	9	10	10	11
		Use Thickness.	1.43	1.54	1.66	1.79	1.93	1.93	2.08
42	2½	Calc. Thick.	*1.12	*1.21	*1.31	1.50	1.72	1.95	2.20
		Use Thickness Class.	2	3	4	5	7	9	10
		Use Thickness.	1.16	1.25	1.35	1.46	1.71	2.00	2.16
	3½	Calc. Thick.	*1.12	*1.21	1.34	1.53	1.74	1.97	2.22
		Use Thickness Class.	2	3	4	6	7	9	10
		Use Thickness.	1.16	1.25	1.35	1.58	1.71	2.00	2.16
	5	Calc. Thick.	*1.21	1.30	1.44	1.61	1.80	2.01	2.24
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.25	1.35	1.46	1.58	1.85	2.00	2.16
	8	Calc. Thick.	1.35	1.46	1.58	1.72	1.90	2.08	2.28
		Use Thickness Class.	4	5	6	7	8	10	11
		Use Thickness.	1.35	1.46	1.58	1.71	1.85	2.16	2.33
	12	Calc. Thick.	1.51	1.61	1.72	1.85	2.01	2.19	2.36
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.46	1.58	1.71	1.85	2.00	2.16	2.33
	16	Calc. Thick.	1.63	1.73	1.84	1.96	2.12	2.27	2.44
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	1.58	1.71	1.85	2.00	2.16	2.33	2.52
48	2½	Calc. Thick.	*1.23	*1.33	*1.45	1.68	1.94	2.21	2.48
		Use Thickness Class.	2	3	4	6	7	9	11
		Use Thickness.	1.27	1.37	1.48	1.73	1.87	2.18	2.54
	3½	Calc. Thick.	*1.24	*1.33	1.50	1.73	1.97	2.23	2.49
		Use Thickness Class.	2	3	4	6	8	9	11
		Use Thickness.	1.27	1.37	1.48	1.73	2.02	2.18	2.54
	5	Calc. Thick.	*1.33	1.44	1.60	1.80	2.03	2.27	2.53
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.37	1.48	1.60	1.87	2.02	2.35	2.54
	8	Calc. Thick.	1.48	1.61	1.76	1.93	2.13	2.34	2.58
		Use Thickness Class.	4	5	6	7	9	10	11
		Use Thickness.	1.48	1.60	1.73	1.87	2.18	2.35	2.54
	12	Calc. Thick.	1.68	1.80	1.92	2.08	2.26	2.45	2.67
		Use Thickness Class.	6	7	7	8	9	11	12
		Use Thickness.	1.73	1.87	1.87	2.02	2.18	2.54	2.74
	16	Calc. Thick.	1.82	1.93	2.05	2.21	2.37	2.55	2.74
		Use Thickness Class.	7	7	8	9	10	11	12
		Use Thickness.	1.87	1.87	2.02	2.18	2.35	2.54	2.74

TABLE 2A.4 (*cont'd*)

Field Condition D

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
54	2½	Calc. Thick.	*1.33	*1.44	1.60	1.88	2.18	2.47	2.77
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.30	1.40	1.63	1.90	2.21	2.39	2.79
	3½	Calc. Thick.	*1.38	*1.48	1.64	1.93	2.20	2.49	2.78
		Use Thickness Class.	2	3	4	6	8	10	11
		Use Thickness.	1.40	1.51	1.63	1.90	2.21	2.58	2.79
	5	Calc. Thick.	*1.43	1.57	1.77	2.00	2.28	2.53	2.81
		Use Thickness Class.	2	4	5	7	8	10	11
		Use Thickness.	1.40	1.63	1.76	2.05	2.21	2.58	2.79
	8	Calc. Thick.	1.63	1.77	1.94	2.15	2.36	2.61	2.88
		Use Thickness Class.	4	5	6	8	9	10	11
		Use Thickness.	1.63	1.76	1.90	2.21	2.39	2.58	2.79
	12	Calc. Thick.	1.85	1.98	2.12	2.31	2.50	2.72	2.98
		Use Thickness Class.	6	7	7	9	10	11	12
		Use Thickness.	1.90	2.05	2.05	2.39	2.58	2.79	3.01
	16	Calc. Thick.	2.01	2.13	2.28	2.43	2.62	2.82	3.05
		Use Thickness Class.	7	8	8	9	10	11	12
		Use Thickness.	2.05	2.21	2.21	2.39	2.58	2.79	3.01
60	2½	Calc. Thick.	*1.43	*1.55	1.75	2.06	2.40	2.73	3.07
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.39	1.50	1.75	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.48	*1.60	1.81	2.11	2.41	2.73	3.07
		Use Thickness Class.	2	3	4	6	8	10	11
		Use Thickness.	1.50	1.62	1.75	2.04	2.38	2.78	3.00
	5	Calc. Thick.	*1.55	*1.77	1.94	2.19	2.48	2.80	3.12
		Use Thickness Class.	2	4	5	7	9	10	12
		Use Thickness.	1.50	1.75	1.89	2.20	2.57	2.78	3.24
	8	Calc. Thick.	1.77	1.92	2.10	2.33	2.58	2.86	3.17
		Use Thickness Class.	4	5	6	8	9	10	12
		Use Thickness.	1.75	1.89	2.04	2.38	2.57	2.78	3.24
	12	Calc. Thick.	2.00	2.14	2.32	2.51	2.73	2.98	3.28
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	2.04	2.20	2.38	2.57	2.78	3.00	3.24
	16	Calc. Thick.	2.16	2.30	2.46	2.65	2.86	3.08	3.34
		Use Thickness Class.	7	8	8	9	10	11	12
		Use Thickness.	2.20	2.38	2.38	2.57	2.78	3.00	3.24

TABLE 2A.5*

Schedule of Barrel Thicknesses—Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	3½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	5	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	8	Calc. Thick.	.26	.27	.28	.29	.30	.31	.32
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	12	Calc. Thick.	.27	.28	.29	.30	.31	.32	.33
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	16	Calc. Thick.	.30	.30	.31	.32	.33	.34	.35
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
4	2½	Calc. Thick.	.27	.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	3½	Calc. Thick.	.27	.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	5	Calc. Thick.	.27	.29	.30	.32	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	8	Calc. Thick.	.30	.31	.32	.33	.35	.36	.38
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	12	Calc. Thick.	.31	.32	.33	.35	.36	.38	.40
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	16	Calc. Thick.	.34	.35	.36	.37	.38	.40	.41
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
6	2½	Calc. Thick.	.32	.33	.35	.38	.41	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	3½	Calc. Thick.	.32	.33	.35	.38	.41	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	5	Calc. Thick.	.33	.35	.37	.39	.42	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	8	Calc. Thick.	.36	.38	.40	.42	.44	.47	.49
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	12	Calc. Thick.	.39	.41	.42	.44	.46	.49	.51
		Use Thickness Class.	1	1	1	1	2	3	3
		Use Thickness.	.43	.43	.43	.43	.46	.50	.50
	16	Calc. Thick.	.43	.44	.46	.47	.49	.51	.53
		Use Thickness Class.	1	1	2	2	3	3	4
		Use Thickness.	.43	.43	.46	.46	.50	.50	.54

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.5 (*cont'd*)

Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
8	2½	Calc. Thick.	*.36	*.38	.41	.45	.49	.53	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	3½	Calc. Thick.	*.35	*.37	.41	.45	.49	.53	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	5	Calc. Thick.	.38	.41	.44	.47	.50	.55	.59
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	8	Calc. Thick.	.43	.45	.48	.50	.53	.57	.61
		Use Thickness Class.	1	1	2	2	3	4	5
		Use Thickness.	.46	.46	.50	.50	.54	.58	.63
	12	Calc. Thick.	.47	.49	.51	.53	.56	.59	.63
		Use Thickness Class.	1	2	2	3	4	4	5
		Use Thickness.	.46	.50	.50	.54	.58	.58	.63
	16	Calc. Thick.	.50	.52	.54	.57	.59	.62	.65
		Use Thickness Class.	2	3	3	4	4	5	5
		Use Thickness.	.50	.54	.54	.58	.58	.63	.63
10	2½	Calc. Thick.	*.43	*.44	.48	.53	.59	.64	.69
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	3½	Calc. Thick.	.42	.45	.50	.55	.59	.64	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	5	Calc. Thick.	.44	.47	.51	.55	.60	.67	.71
		Use Thickness Class.	1	1	1	2	3	5	6
		Use Thickness.	.50	.50	.50	.54	.58	.68	.73
	8	Calc. Thick.	.50	.52	.55	.59	.63	.68	.72
		Use Thickness Class.	1	2	2	3	4	5	6
		Use Thickness.	.50	.54	.54	.58	.63	.68	.73
	12	Calc. Thick.	.56	.58	.61	.64	.67	.71	.76
		Use Thickness Class.	3	3	4	4	5	6	7
		Use Thickness.	.58	.58	.63	.63	.68	.73	.79
	16	Calc. Thick.	.58	.60	.63	.66	.69	.73	.77
		Use Thickness Class.	3	3	4	5	5	6	7
		Use Thickness.	.58	.58	.63	.68	.68	.73	.79
12	2½	Calc. Thick.	*.47	*.49	.53	.59	.66	.72	.79
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	3½	Calc. Thick.	*.46	.49	.55	.60	.67	.72	.80
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	5	Calc. Thick.	.49	.52	.57	.62	.68	.74	.80
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.54	.54	.58	.63	.68	.73	.79
	8	Calc. Thick.	.55	.59	.63	.67	.71	.77	.82
		Use Thickness Class.	1	2	3	4	5	6	7
		Use Thickness.	.54	.58	.63	.68	.73	.79	.85
	12	Calc. Thick.	.61	.64	.67	.71	.75	.80	.85
		Use Thickness Class.	3	3	4	5	5	6	7
		Use Thickness.	.63	.63	.68	.73	.73	.79	.85
	16	Calc. Thick.	.64	.66	.70	.73	.77	.82	.87
		Use Thickness Class.	3	4	4	5	6	7	7
		Use Thickness.	.63	.68	.68	.73	.79	.85	.85

TABLE 2A.5 (*cont'd*)

Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
14	2½	Calc. Thick.	*.51	*.53	.59	.6	.74	.81	.89
		Use Thickness Class.	1	1	2	4	5	6	8
		Use Thickness.	.54	.54	.58	.68	.73	.79	.92
	3½	Calc. Thick.	*.50	.55	.61	.67	.75	.82	.90
		Use Thickness Class.	1	1	3	4	5	7	8
		Use Thickness.	.54	.54	.63	.68	.73	.85	.92
	5	Calc. Thick.	.54	.58	.64	.70	.76	.83	.91
		Use Thickness Class.	1	2	3	4	6	7	8
		Use Thickness.	.54	.58	.63	.68	.79	.85	.92
	8	Calc. Thick.	.62	.65	.70	.75	.81	.87	.93
		Use Thickness Class.	3	3	4	5	6	7	8
		Use Thickness.	.63	.63	.68	.73	.79	.85	.92
	12	Calc. Thick.	.67	.70	.74	.79	.84	.90	.95
		Use Thickness Class.	4	4	5	6	7	8	8
		Use Thickness.	.68	.68	.73	.79	.85	.92	.92
	16	Calc. Thick.	.70	.73	.77	.81	.86	.92	.97
		Use Thickness Class.	4	5	6	6	7	8	9
		Use Thickness.	.68	.73	.79	.79	.85	.92	.99
16	2½	Calc. Thick.	*.55	*.57	.64	.72	.80	.89	.98
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.58	.58	.63	.73	.79	.92	.99
	3½	Calc. Thick.	*.54	.58	.66	.73	.81	.90	.98
		Use Thickness Class.	1	1	3	4	5	7	8
		Use Thickness.	.58	.58	.68	.73	.79	.92	.99
	5	Calc. Thick.	.58	.63	.69	.76	.83	.91	.99
		Use Thickness Class.	1	2	3	5	6	7	8
		Use Thickness.	.58	.63	.68	.79	.85	.92	.99
	8	Calc. Thick.	.66	.70	.76	.81	.87	.94	1.01
		Use Thickness Class.	3	3	5	5	6	7	8
		Use Thickness.	.68	.68	.79	.79	.85	.92	.99
	12	Calc. Thick.	.72	.76	.80	.85	.91	.98	1.05
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.73	.79	.79	.85	.92	.99	1.07
	16	Calc. Thick.	.76	.79	.83	.88	.94	1.00	1.07
		Use Thickness Class.	5	5	6	6	7	8	9
		Use Thickness.	.79	.79	.85	.85	.92	.99	1.07
18	2½	Calc. Thick.	*.59	*.62	.69	.78	.88	.98	1.09
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.63	.63	.68	.79	.85	.99	1.07
	3½	Calc. Thick.	*.59	.63	.71	.80	.89	.99	1.10
		Use Thickness Class.	1	1	3	4	6	7	8
		Use Thickness.	.63	.63	.73	.79	.92	.99	1.07
	5	Calc. Thick.	.62	.68	.75	.83	.91	1.00	1.11
		Use Thickness Class.	1	2	3	5	6	7	8
		Use Thickness.	.63	.68	.73	.85	.92	.99	1.07
	8	Calc. Thick.	.71	.76	.81	.88	.95	1.03	1.13
		Use Thickness Class.	3	4	4	5	6	7	9
		Use Thickness.	.73	.79	.79	.85	.92	.99	1.16
	12	Calc. Thick.	.77	.82	.87	.93	1.00	1.07	1.15
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.79	.85	.85	.92⅝	.99	1.07	1.16
	16	Calc. Thick.	.81	.86	.91	.96	1.02	1.10	1.18
		Use Thickness Class.	4	5	6	7	7	8	9
		Use Thickness.	.79	.85	.92	.99	.99	1.07	1.16

TABLE 2A.5 (*cont'd*)

Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
20	2½	Calc. Thick.	*.62	*.66	.73	.83	.93	1.05	1.17
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.66	.66	.71	.83	.90	1.05	1.13
	3½	Calc. Thick.	*.62	.67	.76	.85	.95	1.06	1.18
		Use Thickness Class.	1	1	3	4	6	7	9
		Use Thickness.	.66	.66	.77	.83	.97	1.05	1.22
	5	Calc. Thick.	.67	.73	.80	.88	.97	1.08	1.19
		Use Thickness Class.	1	2	4	5	6	7	9
		Use Thickness.	.66	.71	.83	.90	.97	1.05	1.22
	8	Calc. Thick.	.75	.80	.86	.92	1.02	1.10	1.21
		Use Thickness Class.	3	4	4	5	7	8	9
		Use Thickness.	.77	.83	.83	.90	1.05	1.13	1.22
	12	Calc. Thick.	.82	.87	.92	.99	1.06	1.13	1.24
		Use Thickness Class.	4	5	5	6	7	8	9
		Use Thickness.	.83	.90	.90	.97	1.05	1.13	1.22
	16	Calc. Thick.	.87	.91	.97	1.03	1.09	1.18	1.27
		Use Thickness Class.	5	5	6	7	8	9	10
		Use Thickness.	.90	.90	.97	1.05	1.13	1.22	1.32
24	2½	Calc. Thick.	*.70	*.74	.82	.95	1.08	1.22	1.35
		Use Thickness Class.	1	1	2	4	6	8	9
		Use Thickness.	.74	.74	.80	.93	1.08	1.26	1.36
	3½	Calc. Thick.	*.70	.76	.86	.97	1.09	1.23	1.36
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.74	.74	.86	1.00	1.08	1.26	1.36
	5	Calc. Thick.	.75	.82	.91	1.01	1.12	1.24	1.37
		Use Thickness Class.	1	2	4	5	6	8	9
		Use Thickness.	.74	.80	.93	1.00	1.08	1.26	1.36
	8	Calc. Thick.	.84	.90	.98	1.07	1.17	1.27	1.40
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.86	.93	1.00	1.08	1.17	1.26	1.36
	12	Calc. Thick.	.92	.98	1.05	1.13	1.21	1.32	1.43
		Use Thickness Class.	4	5	6	7	7	9	10
		Use Thickness.	.93	1.00	1.08	1.17	1.17	1.36	1.47
	16	Calc. Thick.	.98	1.04	1.10	1.18	1.27	1.36	1.47
		Use Thickness Class.	5	6	6	7	8	9	10
		Use Thickness.	1.00	1.08	1.08	1.17	1.26	1.36	1.47
30	2½	Calc. Thick.	*.83	*.89	.99	1.15	1.30	1.48	1.65
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.87	.87	1.02	1.19	1.29	1.50	1.62
	3½	Calc. Thick.	*.83	*.89	1.03	1.17	1.32	1.49	1.65
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.87	.87	1.02	1.19	1.29	1.50	1.62
	5	Calc. Thick.	.89	.98	1.09	1.22	1.36	1.50	1.67
		Use Thickness Class.	1	3	4	5	7	8	9
		Use Thickness.	.87	1.02	1.10	1.19	1.39	1.50	1.62
	8	Calc. Thick.	1.01	1.08	1.18	1.29	1.42	1.56	1.70
		Use Thickness Class.	3	4	5	6	7	9	10
		Use Thickness.	1.02	1.10	1.19	1.29	1.39	1.62	1.75
	12	Calc. Thick.	1.11	1.18	1.25	1.36	1.48	1.61	1.74
		Use Thickness Class.	4	5	6	7	8	9	10
		Use Thickness.	1.10	1.19	1.29	1.39	1.50	1.62	1.75
	16	Calc. Thick.	1.18	1.24	1.32	1.42	1.53	1.64	1.78
		Use Thickness Class.	5	6	6	7	8	9	10
		Use Thickness.	1.19	1.29	1.29	1.39	1.50	1.62	1.75

TABLE 2A.5 (*cont'd*)

Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
36	2½	Calc. Thick.	*.94	*1.01	1.13	1.32	1.52	1.73	1.92
		Use Thickness Class.	1	2	3	5	7	9	10
		Use Thickness.	.97	1.05	1.13	1.32	1.54	1.79	1.93
	3½	Calc. Thick.	*.94	*1.01	1.18	1.35	1.53	1.73	1.93
		Use Thickness Class.	1	2	4	5	7	9	10
		Use Thickness.	.97	1.05	1.22	1.32	1.54	1.79	1.93
	5	Calc. Thick.	1.03	1.12	1.24	1.40	1.58	1.75	1.93
		Use Thickness Class.	2	3	4	6	7	9	10
		Use Thickness.	1.05	1.13	1.22	1.43	1.54	1.79	1.93
	8	Calc. Thick.	1.13	1.23	1.35	1.47	1.64	1.80	1.96
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.13	1.22	1.32	1.43	1.66	1.79	1.93
	12	Calc. Thick.	1.27	1.35	1.44	1.57	1.71	1.85	2.05
		Use Thickness Class.	5	5	6	7	8	9	11
		Use Thickness.	1.32	1.32	1.43	1.54	1.66	1.79	2.08
	16	Calc. Thick.	1.34	1.43	1.53	1.64	1.78	1.93	2.10
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.32	1.43	1.54	1.66	1.79	1.93	2.08
42	2½	Calc. Thick.	*1.05	*1.13	1.27	1.48	1.71	1.93	2.23
		Use Thickness Class.	1	2	3	5	7	9	10
		Use Thickness.	1.07	1.16	1.25	1.46	1.71	2.00	2.16
	3½	Calc. Thick.	*1.06	*1.13	1.31	1.50	1.74	1.95	2.24
		Use Thickness Class.	1	2	4	5	7	9	10
		Use Thickness.	1.07	1.16	1.35	1.46	1.71	2.00	2.16
	5	Calc. Thick.	*1.12	1.23	1.38	1.57	1.78	1.98	2.25
		Use Thickness Class.	2	3	4	6	7	9	11
		Use Thickness.	1.16	1.25	1.35	1.58	1.71	2.00	2.33
	8	Calc. Thick.	1.26	1.37	1.50	1.65	1.85	2.05	2.28
		Use Thickness Class.	3	4	5	7	8	9	11
		Use Thickness.	1.25	1.35	1.46	1.71	1.85	2.00	2.33
	12	Calc. Thick.	1.41	1.51	1.63	1.76	1.93	2.10	2.33
		Use Thickness Class.	5	5	6	7	9	10	11
		Use Thickness.	1.46	1.46	1.58	1.71	2.00	2.16	2.33
	16	Calc. Thick.	1.52	1.61	1.73	1.86	2.02	2.18	2.38
		Use Thickness Class.	6	6	7	8	9	10	11
		Use Thickness.	1.58	1.58	1.71	1.85	2.00	2.16	2.33
48	2½	Calc. Thick.	*1.16	*1.25	1.43	1.68	1.94	2.19	2.50
		Use Thickness Class.	1	2	4	6	7	9	11
		Use Thickness.	1.18	1.27	1.48	1.73	1.87	2.18	2.54
	3½	Calc. Thick.	*1.15	1.27	1.47	1.70	1.95	2.20	2.51
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.18	1.27	1.48	1.73	2.02	2.18	2.54
	5	Calc. Thick.	*1.23	1.38	1.56	1.76	2.00	2.28	2.52
		Use Thickness Class.	2	3	5	6	8	10	11
		Use Thickness.	1.27	1.37	1.60	1.73	2.02	2.35	2.54
	8	Calc. Thick.	1.40	1.53	1.69	1.88	2.08	2.33	2.55
		Use Thickness Class.	3	4	6	7	8	10	11
		Use Thickness.	1.37	1.48	1.73	1.87	2.02	2.35	2.54
	12	Calc. Thick.	1.57	1.68	1.82	1.98	2.18	2.41	2.62
		Use Thickness Class.	5	6	7	8	9	10	11
		Use Thickness.	1.60	1.73	1.87	2.02	2.18	2.35	2.54
	16	Calc. Thick.	1.70	1.80	1.94	2.09	2.28	2.47	2.68
		Use Thickness Class.	6	7	7	8	10	11	12
		Use Thickness.	1.73	1.87	1.87	2.02	2.35	2.54	2.74

TABLE 2A.5 (*cont'd*)

Field Condition E

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
54	2½	Calc. Thick.	*1.26	*1.38	1.58	1.87	2.16	2.47	2.78
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.30	1.40	1.63	1.90	2.21	2.39	2.79
	3½	Calc. Thick.	*1.29	*1.40	1.62	1.90	2.18	2.48	2.79
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.30	1.40	1.63	1.90	2.21	2.39	2.79
	5	Calc. Thick.	*1.36	1.51	1.72	1.98	2.20	2.53	2.80
		Use Thickness Class.	2	3	5	7	8	10	11
		Use Thickness.	1.40	1.51	1.76	2.05	2.21	2.58	2.79
	8	Calc. Thick.	1.51	1.68	1.87	2.08	2.33	2.58	2.85
		Use Thickness Class.	3	4	6	7	9	10	11
		Use Thickness.	1.51	1.63	1.90	2.05	2.39	2.58	2.79
	12	Calc. Thick.	1.74	1.87	2.04	2.21	2.43	2.67	2.92
		Use Thickness Class.	5	6	7	8	9	10	12
		Use Thickness.	1.76	1.90	2.05	2.21	2.39	2.58	3.01
	16	Calc. Thick.	1.88	2.01	2.16	2.34	2.53	2.73	2.98
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	1.90	2.05	2.21	2.39	2.58	2.79	3.01
60	2½	Calc. Thick.	*1.36	*1.48	1.73	2.04	2.38	2.73	3.08
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.39	1.50	1.75	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.40	1.53	1.78	2.08	2.39	2.74	3.09
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.39	1.50	1.75	2.04	2.38	2.78	3.00
	5	Calc. Thick.	*1.47	1.65	1.88	2.15	2.45	2.78	3.10
		Use Thickness Class.	2	3	5	7	8	10	11
		Use Thickness.	1.50	1.62	1.89	2.20	2.38	2.78	3.00
	8	Calc. Thick.	1.68	1.84	2.03	2.28	2.55	2.83	3.13
		Use Thickness Class.	3	5	6	7	9	10	12
		Use Thickness.	1.62	1.89	2.04	2.20	2.57	2.78	3.24
	12	Calc. Thick.	1.90	2.04	2.23	2.43	2.68	2.93	3.23
		Use Thickness Class.	5	6	7	8	10	11	12
		Use Thickness.	1.89	2.04	2.20	2.38	2.78	3.00	3.24
	16	Calc. Thick.	2.07	2.20	2.38	2.56	2.78	3.03	3.30
		Use Thickness Class.	6	7	8	9	10	11	12
		Use Thickness.	2.04	2.20	2.38	2.57	2.78	3.00	3.24

TABLE 2A.6*

Schedule of Barrel Thicknesses—Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
3	2½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	3½	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	5	Calc. Thick.	*.24	*.25	*.25	*.26	.28	.30	.31
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	8	Calc. Thick.	.25	.26	.26	.27	.29	.31	.32
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	12	Calc. Thick.	.27	.27	.29	.30	.31	.32	.33
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
	16	Calc. Thick.	.29	.30	.30	.31	.32	.33	.34
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.37	.37	.37	.37	.37	.37	.37
4	2½	Calc Thick.	.27	.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	3½	Calc. Thick.	.27	.28	.30	.31	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	5	Calc. Thick.	.27	.29	.30	.32	.33	.35	.37
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	8	Calc. Thick.	.30	.31	.32	.33	.35	.36	.38
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	12	Calc. Thick.	.31	.32	.33	.35	.36	.38	.39
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
	16	Calc. Thick.	.32	.33	.35	.36	.37	.39	.40
		Use Thickness Class.	1	1	1	1	1	1	1
		Use Thickness.	.40	.40	.40	.40	.40	.40	.40
6	2½	Calc. Thick.	.32	.33	.35	.38	.41	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	3½	Calc. Thick.	.32	.33	.35	.38	.41	.43	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	5	Calc. Thick.	.32	.33	.35	.38	.41	.45	.48
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	8	Calc. Thick.	.35	.36	.38	.40	.43	.46	.49
		Use Thickness Class.	1	1	1	1	1	2	3
		Use Thickness.	.43	.43	.43	.43	.43	.46	.50
	12	Calc. Thick.	.38	.40	.41	.43	.46	.48	.51
		Use Thickness Class.	1	1	1	1	2	3	3
		Use Thickness.	.43	.43	.43	.43	.46	.50	.50
	16	Calc. Thick.	.41	.42	.44	.46	.48	.50	.52
		Use Thickness Class.	1	1	1	2	3	3	4
		Use Thickness.	.43	.43	.43	.46	.50	.50	.54

* Asterisks preceding calculated thicknesses indicate that in such cases truck load rather than water hammer was controlling.

TABLE 2A.6 (*cont'd*)

Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
8	2½	Calc. Thick.	.35	.37	.41	.45	.49	.53	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	3½	Calc. Thick.	.35	.37	.41	.45	.49	.53	.58
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	5	Calc. Thick.	.37	.40	.43	.46	.50	.55	.59
		Use Thickness Class.	1	1	1	1	2	3	4
		Use Thickness.	.46	.46	.46	.46	.50	.54	.58
	8	Calc. Thick.	.41	.43	.46	.49	.52	.56	.60
		Use Thickness Class.	1	1	1	2	3	4	4
		Use Thickness.	.46	.46	.46	.50	.54	.58	.58
	12	Calc. Thick.	.45	.47	.50	.53	.55	.58	.62
		Use Thickness Class.	1	1	2	3	3	4	5
		Use Thickness.	.46	.46	.50	.54	.54	.58	.63
	16	Calc. Thick.	.48	.50	.52	.54	.57	.60	.63
		Use Thickness Class.	2	2	3	3	4	4	5
		Use Thickness.	.50	.50	.54	.54	.58	.58	.63
10	2½	Calc. Thick.	.41	.44	.48	.53	.59	.64	.69
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	3½	Calc. Thick.	.41	.44	.49	.53	.58	.64	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	5	Calc. Thick.	.43	.46	.50	.55	.60	.65	.70
		Use Thickness Class.	1	1	1	2	3	4	5
		Use Thickness.	.50	.50	.50	.54	.58	.63	.68
	8	Calc. Thick.	.48	.51	.54	.57	.62	.67	.71
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.50	.50	.54	.58	.63	.68	.73
	12	Calc. Thick.	.52	.55	.58	.61	.65	.69	.73
		Use Thickness Class.	1	2	3	4	4	5	6
		Use Thickness.	.50	.54	.58	.63	.63	.68	.73
	16	Calc. Thick.	.55	.57	.60	.63	.67	.71	.75
		Use Thickness Class.	2	3	3	4	5	6	6
		Use Thickness.	.54	.58	.58	.63	.68	.73	.73
12	2½	Calc. Thick.	*.44	.48	.53	.59	.66	.72	.79
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	3½	Calc. Thick.	.44	.48	.54	.60	.66	.72	.79
		Use Thickness Class.	1	1	1	2	4	5	6
		Use Thickness.	.54	.54	.54	.58	.68	.73	.79
	5	Calc. Thick.	.47	.51	.56	.61	.67	.73	.80
		Use Thickness Class.	1	1	2	3	4	5	6
		Use Thickness.	.54	.54	.58	.63	.68	.73	.79
	8	Calc. Thick.	.53	.56	.60	.65	.70	.76	.81
		Use Thickness Class.	1	2	2	3	4	5	6
		Use Thickness.	.54	.58	.58	.63	.68	.73	.79
	12	Calc. Thick.	.57	.60	.64	.68	.73	.78	.83
		Use Thickness Class.	2	2	3	4	5	6	7
		Use Thickness.	.58	.58	.63	.68	.73	.79	.85
	16	Calc. Thick.	.60	.63	.66	.70	.74	.79	.84
		Use Thickness Class.	2	3	4	4	5	6	7
		Use Thickness.	.58	.63	.68	.68	.73	.79	.85

TABLE 2A.6 (*cont'd*)

Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
14	2½	Calc. Thick.	*.48	.52	.59	.66	.74	.81	.89
		Use Thickness Class.	1	1	2	4	5	6	8
		Use Thickness.	.54	.54	.58	.68	.73	.79	.92
	3½	Calc. Thick.	.48	.54	.60	.66	.74	.82	.90
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.54	.54	.58	.68	.73	.85	.92
	5	Calc. Thick.	.51	.56	.62	.68	.75	.82	.90
		Use Thickness Class.	1	2	3	4	5	7	8
		Use Thickness.	.54	.58	.63	.68	.73	.85	.92
	8	Calc. Thick.	.58	.62	.66	.72	.78	.85	.92
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.58	.63	.68	.73	.79	.85	.92
	12	Calc. Thick.	.63	.66	.71	.76	.81	.87	.93
		Use Thickness Class.	3	4	5	6	6	7	8
		Use Thickness.	.63	.68	.73	.79	.79	.85	.92
	16	Calc. Thick.	.65	.69	.73	.77	.83	.88	.94
		Use Thickness Class.	3	4	5	6	7	7	8
		Use Thickness.	.63	.68	.73	.79	.85	.85	.92
16	2½	Calc. Thick.	*.51	.56	.63	.72	.80	.89	.98
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.58	.58	.63	.73	.79	.92	.99
	3½	Calc. Thick.	.51	.57	.64	.72	.81	.89	.98
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.58	.58	.63	.73	.79	.92	.99
	5	Calc. Thick.	.55	.60	.67	.74	.81	.90	.99
		Use Thickness Class.	1	1	3	4	5	7	8
		Use Thickness.	.58	.58	.68	.73	.79	.92	.99
	8	Calc. Thick.	.62	.66	.72	.78	.85	.92	1.00
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.63	.68	.73	.79	.85	.92	.99
	12	Calc. Thick.	.66	.71	.76	.81	.88	.95	1.01
		Use Thickness Class.	3	4	5	5	6	7	8
		Use Thickness.	.68	.73	.79	.79	.85	.92	.99
	16	Calc. Thick.	.70	.74	.79	.84	.90	.97	1.03
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.68	.73	.79	.85	.92	.99	1.07
18	2½	Calc. Thick.	*.54	.61	.68	.78	.88	.98	1.09
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.63	.63	.68	.79	.85	.99	1.07
	3½	Calc. Thick.	*.54	.61	.70	.78	.88	.98	1.10
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.63	.63	.68	.79	.85	.99	1.07
	5	Calc. Thick.	.60	.66	.72	.81	.90	.99	1.10
		Use Thickness Class.	1	2	3	4	6	7	8
		Use Thickness.	.63	.68	.73	.79	.92	.99	1.07
	8	Calc. Thick.	.66	.71	.77	.85	.92	1.01	1.11
		Use Thickness Class.	2	3	4	5	6	7	8
		Use Thickness.	.68	.73	.79	.85	.92	.99	1.07
	12	Calc. Thick.	.71	.76	.82	.89	.96	1.04	1.13
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.73	.79	.85	.92	.99	1.07	1.16
	16	Calc. Thick.	.75	.80	.85	.91	.98	1.06	1.15
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.73	.79	.85	.92	.99	1.07	1.16

TABLE 2A.6 (*cont'd*)

Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
20	2½	Calc. Thick.	*.57	.62	.72	.82	.93	1.05	1.16
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.66	.66	.71	.83	.90	1.05	1.13
	3½	Calc. Thick.	*.57	.64	.73	.83	.93	1.05	1.17
		Use Thickness Class.	1	1	2	4	5	7	8
		Use Thickness.	.66	.66	.71	.83	.90	1.05	1.13
	5	Calc. Thick.	.62	.69	.77	.86	.96	1.06	1.18
		Use Thickness Class.	1	2	3	4	6	7	9
		Use Thickness.	.66	.71	.77	.83	.97	1.05	1.22
	8	Calc. Thick.	.69	.75	.82	.90	.98	1.08	1.19
		Use Thickness Class.	2	3	4	5	6	7	9
		Use Thickness.	.71	.77	.83	.90	.97	1.05	1.22
	12	Calc. Thick.	.76	.81	.87	.94	1.02	1.10	1.21
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.77	.83	.90	.97	1.05	1.13	1.22
	16	Calc. Thick.	.80	.85	.91	.97	1.05	1.13	1.23
		Use Thickness Class.	4	4	5	6	7	8	9
		Use Thickness.	.83	.83	.90	.97	1.05	1.13	1.22
24	2½	Calc. Thick.	*.64	.71	.82	.95	1.08	1.22	1.35
		Use Thickness Class.	1	1	2	4	6	8	9
		Use Thickness.	.74	.74	.80	.93	1.08	1.26	1.36
	3½	Calc. Thick.	*.64	.71	.83	.96	1.08	1.23	1.36
		Use Thickness Class.	1	1	3	4	6	8	9
		Use Thickness.	.74	.74	.86	.93	1.08	1.26	1.36
	5	Calc. Thick.	.69	.78	.88	.98	1.10	1.24	1.37
		Use Thickness Class.	1	2	3	5	6	8	9
		Use Thickness.	.74	.80	.86	1.00	1.08	1.26	1.36
	8	Calc. Thick.	.76	.84	.92	1.02	1.13	1.26	1.39
		Use Thickness Class.	1	3	4	5	7	8	9
		Use Thickness.	.74	.86	.93	1.00	1.17	1.26	1.36
	12	Calc. Thick.	.84	.91	.98	1.07	1.17	1.28	1.40
		Use Thickness Class.	3	4	5	6	7	8	9
		Use Thickness.	.86	.93	1.00	1.08	1.17	1.26	1.36
	16	Calc. Thick.	.89	.95	1.02	1.11	1.20	1.31	1.43
		Use Thickness Class.	3	4	5	6	7	9	10
		Use Thickness.	.86	.93	1.00	1.08	1.17	1.36	1.47
30	2½	Calc. Thick.	*.74	.83	.98	1.14	1.30	1.48	1.64
		Use Thickness Class.	1	1	3	4	6	8	9
		Use Thickness.	.87	.87	1.02	1.10	1.29	1.50	1.62
	3½	Calc. Thick.	*.74	.87	1.00	1.16	1.31	1.49	1.64
		Use Thickness Class.	1	1	3	5	6	8	9
		Use Thickness.	.87	.87	1.02	1.19	1.29	1.50	1.62
	5	Calc. Thick.	.83	.93	1.05	1.18	1.33	1.50	1.65
		Use Thickness Class.	1	2	3	5	6	8	9
		Use Thickness.	.87	.94	1.02	1.19	1.29	1.50	1.62
	8	Calc. Thick.	.91	1.00	1.10	1.23	1.37	1.53	1.67
		Use Thickness Class.	2	3	4	5	7	8	9
		Use Thickness.	.94	1.02	1.10	1.19	1.39	1.50	1.62
	12	Calc. Thick.	1.00	1.08	1.17	1.28	1.42	1.55	1.70
		Use Thickness Class.	3	4	5	6	7	8	10
		Use Thickness.	1.02	1.10	1.19	1.29	1.39	1.50	1.75
	16	Calc. Thick.	1.04	1.13	1.23	1.33	1.44	1.58	1.73
		Use Thickness Class.	3	4	5	6	7	9	10
		Use Thickness.	1.02	1.10	1.19	1.29	1.39	1.62	1.75

TABLE 2A.6 (*cont'd*)

Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
36	2½	Calc. Thick.	*.83	.93	1.12	1.33	1.52	1.73	1.93
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	.97	.97	1.13	1.32	1.54	1.79	1.93
	3½	Calc. Thick.	.86	.98	1.13	1.33	1.53	1.73	1.93
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	.97	.97	1.13	1.32	1.54	1.79	1.93
	5	Calc. Thick.	.92	1.03	1.18	1.36	1.53	1.74	1.93
		Use Thickness Class.	1	2	4	5	7	9	10
		Use Thickness.	.97	1.05	1.22	1.32	1.54	1.79	1.93
	8	Calc. Thick.	1.02	1.13	1.26	1.40	1.58	1.76	1.95
		Use Thickness Class.	2	3	4	6	7	9	10
		Use Thickness.	1.05	1.13	1.22	1.43	1.54	1.79	1.93
	12	Calc. Thick.	1.12	1.22	1.33	1.47	1.63	1.80	1.98
		Use Thickness Class.	3	4	5	6	8	9	10
		Use Thickness.	1.13	1.22	1.32	1.43	1.66	1.79	1.93
	16	Calc. Thick.	1.19	1.29	1.40	1.53	1.66	1.83	2.03
		Use Thickness Class.	4	5	6	7	8	9	11
		Use Thickness.	1.22	1.32	1.43	1.54	1.66	1.79	2.08
42	2½	Calc. Thick.	*.89	*1.03	1.24	*1.48	1.70	1.94	2.23
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	1.07	1.07	1.25	1.46	1.71	2.00	2.16
	3½	Calc. Thick.	*.92	1.06	1.27	1.48	1.73	1.95	2.23
		Use Thickness Class.	1	1	3	5	7	9	10
		Use Thickness.	1.07	1.07	1.25	1.46	1.71	2.00	2.16
	5	Calc. Thick.	1.01	1.16	1.31	1.51	1.74	1.96	2.24
		Use Thickness Class.	1	2	4	5	7	9	10
		Use Thickness.	1.07	1.16	1.35	1.46	1.71	2.00	2.16
	8	Calc. Thick.	1.12	1.24	1.38	1.57	1.78	1.98	2.25
		Use Thickness Class.	2	3	4	6	8	9	11
		Use Thickness.	1.16	1.25	1.35	1.58	1.85	2.00	2.33
	12	Calc. Thick.	1.23	1.35	1.48	1.65	1.84	2.03	2.27
		Use Thickness Class.	3	4	5	7	8	9	11
		Use Thickness.	1.25	1.35	1.46	1.71	1.85	2.00	2.33
	16	Calc. Thick.	1.32	1.43	1.55	1.70	1.88	2.06	2.30
		Use Thickness Class.	4	5	6	7	8	9	11
		Use Thickness.	1.35	1.46	1.58	1.71	1.85	2.00	2.33
48	2½	Calc. Thick.	*.98	1.18	1.43	1.68	1.93	2.19	2.50
		Use Thickness Class.	1	1	4	6	7	9	11
		Use Thickness.	1.18	1.18	1.48	1.73	1.87	2.18	2.54
	3½	Calc. Thick.	*.98	1.18	1.43	1.68	1.93	2.20	2.50
		Use Thickness Class.	1	1	4	6	7	9	11
		Use Thickness.	1.18	1.18	1.48	1.73	1.87	2.18	2.54
	5	Calc. Thick.	1.12	1.27	1.48	1.71	1.95	2.21	2.51
		Use Thickness Class.	1	2	4	6	8	9	11
		Use Thickness.	1.18	1.27	1.48	1.73	2.02	2.18	2.54
	8	Calc. Thick.	1.23	1.38	1.56	1.76	2.00	2.28	2.53
		Use Thickness Class.	2	3	5	6	8	10	11
		Use Thickness.	1.27	1.37	1.60	1.73	2.02	2.35	2.54
	12	Calc. Thick.	1.36	1.50	1.66	1.83	2.05	2.32	2.55
		Use Thickness Class.	3	4	5	7	8	10	11
		Use Thickness.	1.37	1.48	1.60	1.87	2.02	2.35	2.54
	16	Calc. Thick.	1.46	1.59	1.74	1.91	2.12	2.34	2.58
		Use Thickness Class.	4	5	6	7	9	10	11
		Use Thickness.	1.48	1.60	1.73	1.87	2.18	2.35	2.54

TABLE 2A.6 (*cont'd*)

Field Condition F

S = 11,000 lb. per sq.in. R = 31,000 lb. per sq.in.

NOMINAL DIAM., INCH	DEPTH OF COVER, FEET		INTERNAL PRESSURE—LB. PER SQ.IN.						
			50	100	150	200	250	300	350
			Barrel thicknesses in inches						
54	2½	Calc. Thick.	*1.05	1.28	1.58	1.87	2.16	2.48	2.78
		Use Thickness Class.	1	1	4	6	8	9	11
		Use Thickness.	1.30	1.30	1.63	1.90	2.21	2.39	2.79
	3½	Calc. Thick.	1.10	1.33	1.58	1.87	2.17	2.48	2.78
		Use Thickness Class.	1	1	4	6	8	9	11
		Use Thickness.	1.30	1.30	1.63	1.90	2.21	2.39	2.79
	5	Calc. Thick.	1.20	1.40	1.61	1.90	2.18	2.49	2.79
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.30	1.40	1.63	1.90	2.21	2.58	2.79
	8	Calc. Thick.	1.36	1.52	1.72	1.97	2.23	2.53	2.82
		Use Thickness Class.	2	3	5	6	8	10	11
		Use Thickness.	1.40	1.51	1.76	1.90	2.21	2.58	2.79
	12	Calc. Thick.	1.49	1.64	1.85	2.05	2.31	2.58	2.84
		Use Thickness Class.	3	4	6	7	9	10	11
		Use Thickness.	1.51	1.63	1.90	2.05	2.39	2.58	2.79
	16	Calc. Thick.	1.61	1.75	1.93	2.13	2.37	2.63	2.88
		Use Thickness Class.	4	5	6	8	9	10	11
		Use Thickness.	1.63	1.76	1.90	2.21	2.39	2.58	2.79
60	2½	Calc. Thick.	*1.13	1.40	1.70	2.03	2.38	2.72	3.08
		Use Thickness Class.	1	1	4	6	8	10	11
		Use Thickness.	1.39	1.39	1.75	2.04	2.38	2.78	3.00
	3½	Calc. Thick.	*1.18	1.43	1.72	2.05	2.39	2.73	3.09
		Use Thickness Class.	1	1	4	6	8	10	11
		Use Thickness.	1.39	1.39	1.75	2.04	2.38	2.78	3.00
	5	Calc. Thick.	1.30	1.53	1.78	2.08	2.43	2.74	3.09
		Use Thickness Class.	1	2	4	6	8	10	11
		Use Thickness.	1.39	1.50	1.75	2.04	2.38	2.78	3.00
	8	Calc. Thick.	1.46	1.66	1.88	2.16	2.47	2.76	3.10
		Use Thickness Class.	2	3	5	7	8	10	11
		Use Thickness.	1.50	1.62	1.89	2.20	2.38	2.78	3.00
	12	Calc. Thick.	1.63	1.80	2.00	2.24	2.53	2.83	3.14
		Use Thickness Class.	3	4	6	7	9	10	12
		Use Thickness.	1.62	1.75	2.04	2.20	2.57	2.78	3.24
	16	Calc. Thick.	1.76	1.92	2.10	2.33	2.58	2.86	3.17
		Use Thickness Class.	4	5	6	8	9	10	12
		Use Thickness.	1.75	1.89	2.04	2.38	2.57	2.78	3.24

ASA
A21.2-1939

American Standard

SPECIFICATIONS
for
CAST IRON PIT CAST PIPE FOR WATER OR OTHER LIQUIDS

Approved by
American Standards Association
December, 1939

SPONSORS

American Gas Association
American Society for Testing Materials
American Water Works Association
New England Water Works Association

AMERICAN ENGINEERING AND INDUSTRIAL STANDARDS

Approved by New England Water Works Association September 12, 1939

Users of this document should make reference to "American Recommended Practice Manual for the Computation of Strength and Thickness of Cast Iron Pipe (A.S.A., A21.1–1939)" for complete information concerning the conditions which various thicknesses of pipe are designed to meet. The foreword of the Manual also contains a statement regarding the history of the specifications and references to other related documents.

AMERICAN STANDARD SPECIFICATIONS
for
CAST IRON PIT CAST PIPE FOR WATER OR OTHER LIQUIDS

This specification covers cast iron pit cast pipe for water or other liquids. Pit cast pipe are pipe cast vertically with dry sand molds and cores.

Sect. 2-1. Description of Pipe. The pipe shall be made with bell and spigot ends, plain ends or such other type of ends as may be agreed upon at the time of purchase. Pipe with bell and spigot ends shall conform accurately to the dimensions given in Table 1. Pipe with other types of ends shall comply with the dimensions agreed upon but in all other respects shall fulfill the specifications hereinafter given. Pipe shall be straight and shall be true circles in section, with their inner and outer surfaces concentric. They shall be at least 12 ft. in nominal laying length, except as provided for cut pipe in Sect. 2-10.

Sect. 2-2. Casting of Pipe. The pipe shall be cast in dry sand molds in a vertical position. Pipe 16 inches or less in diameter shall be cast with the bell end up or down as specified in the proposals. Pipe 18 inches or more in diameter shall be cast with the bell end down. The pipe shall not be stripped or taken from the pit while showing color of heat, but shall be left in the flasks for a sufficient length of time to prevent unequal contraction by subsequent exposure.

Sect. 2-3. Quality of Iron.

(a) All pipes shall be made of cast iron of good quality, and of such character and so adapted in chemical composition to the thickness of the pipe to be cast, that the iron in the pipe shall be strong, tough, resilient, of even grain and soft enough for satisfactory

drilling and cutting and it shall comply with the physical specifications given in Sect. 2-16, 2-17 and 2-18. The metal shall be remelted in a cupola or other suitable furnace.

(b) The iron in the pipe shall not contain more than 0.90 per cent of phosphorus nor more than 0.10 per cent of sulphur. Samples for chemical analysis shall be taken by drilling completely through from skin to skin each of the acceptance test specimens; but not to exceed three specimens per heat.

Sect. 2-4. Quality of Castings. The pipe shall be smooth, free from scales, lumps, blisters, sand holes and defects of every nature which unfit them for the use for which they are intended. No plugging, filling, burning-in or welding will be allowed except as permitted by the purchaser.

Sect. 2-5. Foundry Records.

(a) Casting—A record of the melting and pouring temperatures of the iron shall be furnished the purchaser if requested.

(b) Chemical analyses shall be made by the manufacturer from each heat to determine total carbon, manganese, phosphorus, sulphur and silicon; duplicate copies of test reports shall be furnished the purchaser on request.

Sect. 2-6. Marking Pipe. Every pipe shall have distinctly cast upon it the initials of the maker's name. When cast especially to order, each pipe larger than 4-inch may also have cast upon it figures showing the year in which it was cast and a number signifying the order in point of time in which it was cast, the figures denoting the year being above and the number below, thus:

1940	1940	1940
1	2	3

etc., also any initials, not exceeding four, which may be required by the purchaser. The letters and figures shall be cast on the outside and shall have dimensions as indicated below.

Diameters of Pipe, Inches, Inclusive	Height of Letter, Inches	Relief, Inch
3 to 10	$\frac{3}{4}$	$\frac{3}{32}$
12 to 20	$1\frac{1}{4}$	$\frac{3}{32}$
24 & larger	$1\frac{3}{4}$	$\frac{1}{8}$

The weight and the class shall be conspicuously painted in white in the inside or outside of each pipe after the coating has become hard.

Sect. 2-7. Inspection by Purchaser.

(a) *Definition of Word "Purchaser."* Wherever the word "Purchaser" is used herein it shall be understood to mean the actual purchaser of the pipe or his authorized agents acting within the scope of the duties entrusted to them.

(b) *Power of Purchaser to Inspect.* The purchaser shall have free access at all times to all parts of any manufacturing plant which concern the manufacture of articles to be made for him. He may inspect the material, the pattern work, molding, casting, coating and lining of the pipe. The forms, sizes, uniformity and conditions of all pipe herein referred to shall be subject to his inspection and approval, and he may reject, without subjection to hydrostatic test, any pipe which is not in conformity with the specifications or drawings. Any pipe rejected shall be marked "rejected" and any marks pertaining to the purchaser shall be chipped or erased from such pipe.

(c) *Manufacturer to Furnish Men and Material.* The manufacturer shall provide all tools, testing equipment, materials, labor and facilities necessary for the required testing, inspection and weighing of the pipe at the foundry.

(d) *Report of Purchaser's Inspection.* The purchaser shall make written report daily at the foundry office of all pipe rejected, noting causes for rejection.

Sect. 2-8. Inspection and Certification by Manufacturer. Should the purchaser have no inspector at the works, the manufacturer shall, if required by the purchaser, furnish a sworn statement that the inspection and all of the tests have been made as specified, this statement to contain the results of all specified tests.

Sect. 2-9. Pipe to Be Delivered Sound. All the pipe must be delivered in all respects sound and comformable to these specifications. The inspection shall not relieve the manufacturer of any of his obligations in this respect, and any defective pipe which may have passed the purchaser at the works or elsewhere shall be at all times liable to rejection when discovered, until the final completion and adjustment of the contract; provided, however, that the manufacturer shall not be held liable for pipe found to be cracked after they have been accepted at the agreed point of delivery, unless there shall be unmistakable evidence that the casting was originally defective or damaged before acceptance. Care shall be taken in handling the pipe not to injure the coating or lining and no pipe or other material

of any kind shall be placed in the pipe during transportation or at any other time after they have received the coating or lining.

Sect. 2-10. Cut Pipe. Defective spigot ends on pipe may be cut off in a manner which will produce a square end. Cut pipe shall be shipped with plain ends or shall have an iron or steel band shrunk into a groove or welded securely on the pipe, as may be agreed upon at time of purchase. Not more than 8 per cent of the total number of pipe of each size shall be cut, and no cut pipe shall be furnished which is less than 11 ft. 0 in. in laying length, unless it has been used by purchaser's order for strip and ring tests in which case a length of not less than 10 ft. 0 in. shall be accepted.

Sect. 2-11. Tolerances or Maximum Permitted Variations from Standard.

(a) *Tolerances in Diameter of Pipe and Sockets.* Outside diameters of pipe barrels and spigot beads and diameters of sockets shall be kept as nearly as practicable to the specified dimensions. They shall be tested with circular gauges. Tolerances or maximum permitted variations from standard dimensions are listed below:

Nominal Diameter in Inches	Tolerance, Plus or Minus, in Inches
3 to 16	.06
18, 20 & 24	.08
30, 36 & 42	.10
48	.12
54	.15
60	.15

(b) *Tolerances in Thickness.* The tolerances, or maximum permitted variations from standard in thickness of pipe and in dimensions of bells are listed below:

Nominal Diameter in Inches, inclusive	Tolerance, Plus or Minus, in Inches
3 to 8	.07
10 to 24	.08
30 to 60	.10

NOTE: In pipe barrel thickness, tolerances .02 inch greater than those listed above shall be permissible over areas not exceeding 8 inches in length in any direction.

(c) *Allowable Percentage of Variation in Weight.* The weight of no single pipe shall be less than the nominal tabulated weight by more than 5% for pipe 16 inches or less in diameter, and 4% for pipe more than 16 inches in diameter. The total excess weight to be paid for on orders of 25 tons or more shall not exceed 2% of the nominal weight, and on orders less than 25 tons shall not exceed 5% of the nominal weight. An order is hereby defined as including all the pipe ordered under the terms of a specific contract or purchase order or a single order placed under the terms of a standing contract.

Sect. 2-12. Cleaning and Inspecting. All pipe shall have gates, fins and other roughnesses chipped or ground off and shall be thoroughly cleaned, checked as to dimensions and also subjected to a careful surface inspection, a hammer test, and a rolling test, before being coated or lined.

Sect. 2-13. Hydrostatic Test. Each pipe shall be subjected to a hydrostatic proof test. This test may be made either before or after the tar dip or the priming coat for bituminous enamel has been applied but shall be made before the cement mortar lining, bituminous enamel lining, or any other special lining has been applied to pipe for which such a lining is specified.

The pipe shall be under the test pressure for at least one-half minute, and while under pressure shall be subjected to a hammer or shock test. Any pipe showing defects by leaking, sweating, or otherwise, shall be rejected. The test pressures shall be in accordance with the table on the following page.

Sect. 2-14. Weighing. Each length of pipe shall be weighed and the weight and class plainly marked on the outside or inside of the bell or spigot end. Pipe which is to be lined with cement mortar or coated on the inside or outside, or both, with bituminous enamel or other special material shall be weighed before the application of such a lining or coating. If desired by the purchaser, pipe not lined or coated with cement mortar, bituminous enamel or other special material shall be weighed after delivery and the weights so ascertained shall be used in the final settlement, provided such weighing is done by a legalized weigh master. Unless otherwise stated in the contract, a ton shall be 2,000 lb. avoirdupois.

Sect. 2-15. Linings and Exterior Coatings. Any lining or coating which is to be applied to the pipe, shall be specified in the agreement made at time of purchase. Separate specifications for the following linings and coatings have been or will be provided in

TABLE OF PRESSURES FOR HYDROSTATIC TESTS

Nominal Diameter of Pipe, Inches	Barrel Thickness, Inches		Test Pressures, Lb. per sq.in.
	From	To	
3 to 12	All Thicknesses		400
14	.50	.70	300
14	.71	.85	350
14	.86	1.20	450
16	.55	.75	300
16	.76	.95	350
16	.96	1.25	450
18	.60	.80	300
18	.81	1.00	350
18	1.01	1.35	450
20	.65	.85	250
20	.86	1.05	350
20	1.06	1.45	450
24	.70	.90	200
24	.91	1.00	300
24	1.01	1.60	400
30	.85	1.05	200
30	1.06	1.30	300
30	1.31	1.75	400
36	.95	1.15	200
36	1.16	1.45	300
36	1.46	1.95	350
42	1.05	1.35	200
42	1.36	1.60	300
42	1.61	1.75	350
48	1.15	1.50	200
48	1.51	1.90	300
48	1.91	2.05	350
54	1.30	1.55	200
54	1.56	1.80	250
54	1.81	2.05	300
54	2.06	2.25	350
60	1.35	1.75	200
60	1.76	2.05	250
60	2.06	2.30	300
60	2.31	2.40	350

Note: Unless otherwise arranged between the manufacturer and the purchaser, pipe thicker than those listed in the above table shall be tested at the highest pressures listed for the given diameter.

connection with these specifications for pipe:

1. Cement Mortar Lining (A21.4-1939)
2. Coal Tar Dip (in preparation)
3. { Bituminous Enamel Lining
   { Bituminous Enamel Exterior Coating

Sect. 2-16. Tests of Material. The acceptability of iron used in cast iron pipe as regards physical characteristics shall be determined by the testing of bars cast from the same iron as the pipe, or, if specified by the purchaser, by the testing of Talbot strips and/or rings cut from the pipe as described in Sect. 2-18. Such strip and/or ring tests shall be paid for by the purchaser at prices to be agreed upon. In any case the test bars shall be made and tested and results given to the purchaser if requested. The smallest pipe on which ring tests may be required is the 6-inch. The observations and the computed results hereinafter required shall be recorded and if requested reported to the purchaser.

Sect. 2-17. Test Bars.

(a) *Dimensions.* Test bars shall be 2 inches wide, 1 inch thick, and not less than 26 inches long. Individual test bars may vary as much as 2 per cent from standard width, or standard thickness, or both, but the patterns and molding practice shall be such that the errors shall in general not exceed 1 per cent.

(b) *Methods of Casting.* The bars shall be cast vertically in well-faced, dry sand molds provided with suitable pouring basin and mounted on a suitable refractory foundation. Metal for the bars shall be obtained by using a small heated ladle taking its metal from the main ladle from which the pipe is to be poured and after all alloys and other additional metal, except cast iron pipe for cooling, have been added to the main ladle and become melted. The bars shall not be removed from the mold before they have cooled to 500°F.

(c) *When Cast and to What Pipe Applicable.* Except as hereinafter provided for special cases, one pair of test bars of the metal used shall be cast with iron from the first ladle, another pair with iron from the approximately middle ladle, and a third pair with iron from the last ladle of iron taken during a day's run or heat from the cupola in which the iron for the pipe is melted. If the heat lasts for more than 6 hours, then additional pairs of bars shall be cast at approximately uniform intervals so as to give an extra pair of bars for each 3 hours during which the heat lasts in excess of 6 hours.

In case the charging of the cupola is to be changed one or more times during the day's run or heat in order to produce a different iron, the time of taking test bars shall be varied in such a way as to obtain representative tests of the iron at least at the beginning and end of each period during which the iron is intended to be constant in quality; and in case such period exceeds four hours additional pairs of bars shall be taken at such times as will provide a pair of bars for each two hours during which this special mixture is used. At least one bar from each pair shall be broken, but the manufacturer shall have the right to break both bars in which case the better bar shall be taken as representative. Bars showing flaws in fracture may be disregarded.

(d) *Test Bar Requirements to Indicate Acceptable Iron; Retests may be made at Contractor's Option using Talbot Strips and/or Rings.* In order that the iron shall be acceptable the average results from the single bars representing the respective pairs of bars cast during the heat or period shall comply with the requirements hereinafter specified and, in addition, no representative bar shall be more than 5 percent below the minimum requirements in either corrected breaking load or corrected deflection. In case the test bars do not measure up to these requirements the manufacturer may make one or more Talbot strip tests and/or ring tests of specimens cut from such of the pipe as may be agreed upon as best representing the iron at the time when the deficient test bars were cast. In the absence of the purchaser the manufacturer may select the pipe from which rings and/or strips shall be cut. The results from these rings and/or strips shall be kept as a foundry record available to any purchaser who requires a report of tests on the 2-inch by 1-inch bars. Any Talbot strip tests or ring tests made under this provision shall be at the expense of the manufacturer. If these supplementary Talbot strip tests and/or ring tests do not meet the requirements, the pipe cast in that heat or period, or such a part thereof as may be agreed to by the purchaser, shall be rejected.

(e) *Method of Testing.* The bars shall be broken as beams by placing them flatwise on supports 24 inches apart and applying the load at the center of the span. The breaking load and the corresponding deflection shall be observed and recorded.

(f) *Correcting Observed Breaking Loads and Deflections.* The bars shall be measured at the point of application of the load and the results corrected to standard 2 inch by 1 inch cross section by the

conventional beam formula as follows:

Corrected breaking load = observed breaking load multiplied by $\frac{2}{bd^2}$

Corrected deflection at breaking = observed deflection at breaking multiplied by d

where b = measured width and

d = measured depth

of the bar at point of application of load

In the formulae above the deflection and all dimensions are in inches.

(g) *Requirements as to Strength and Deflection of 2 inch by 1 inch Bars.* In order to indicate acceptable metal, the corrected breaking loads and deflections of the representative 2 inch by 1 inch test bars for a given heat or period interpreted as provided in paragraph (d) above, shall comply with such of the following tabulated requirements as pertain to the thickness range within which fall the particular pipes which are under consideration.

TABLE OF MINIMUM CORRECTED BREAKING LOADS & DEFLECTIONS

Metal Thickness of Pipe, Inch	Minimum Center Breaking Load, Pounds	Minimum Center Deflection at Breaking, Inch
Below .61	1900	.30 + .0001 (Breaking Load − 1900)
.61 to .90	2000	.30 + .0001 (Breaking Load − 2000)
.91 to 1.60	2200	.30 + .0001 (Breaking Load − 2200)
1.61 to 2.50	2300	.30 + .0001 (Breaking Load − 2300)

Note: For thicknesses exceeding 2.50 inches the form of test specimen and the test requirements shall be as agreed upon in the purchase contract.

Sect. 2-18. Talbot Strip Tests and Ring Tests.

(a) *Dimensions.* Rings shall have a length equal to half the nominal diameter of the pipe unless the diameter exceeds 24 inches, in which case the length of ring shall be 12 inches. Strips shall be not less than 11 inches long and for 24-inch and larger pipe may be cut from the least stressed portions of rings (see Sect. 2-18 (d) after the rings have been broken. The end 2 inches of the pipe shall not be included in ring or strip.

Note: To make both ring and strip tests on a pipe will therefore require at the least (on 6 inch pipe) 16 inches of pipe, at the most (on 20 inch pipe) 23 inches of pipe, and on pipe larger than 20 inches, 14 inches of pipe.

(b) *Method of Sampling.* The purchaser who has expressly specified Talbot strip tests and/or ring tests as acceptance tests of the

pipe may select at random from each run, or heat, one or more pipe from which test specimens are to be cut. In the absence of the purchaser or his representative, the pipe from which test specimens are to be taken may be selected by the manufacturer. If the purchaser should wish to test the uniformity of a run or heat, he may divide it into two or more periods and have a separate set of acceptance tests for pipe in each period.

(c) *Defective Specimens; Retests.* If any test specimen shows defective machining or obvious lack of continuity of metal, it shall be discarded and replaced by another specimen selected by the purchaser. If the test specimens first selected fail to meet the requirements specified hereinafter and the purchaser permits a retest, at least twice the number of specimens that failed shall be selected by the purchaser for retest from a pipe cast in the same run or period. In case a ring from a pipe 24 inches in diameter or larger fails to

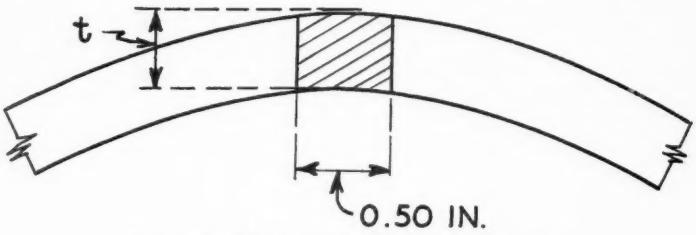


FIG. 1. Position from which Talbot Strip Is Cut

meet specifications, the purchaser may accept strip tests, two specimens to be cut from the failed ring at points of low stress as described in Sect. 2-18 (d). In any case of retest the pipe cast during the run or period shall be acceptable only when all retest specimens meet the requirements. All retests shall be made at the expense of the manufacturer.

(d) *Talbot Strip Tests.* Two Talbot strips shall be machined longitudinally from each pipe selected by the purchaser for testing by this method. If ring tests are also made and the pipe are 24 inches or larger these Talbot strips may be cut from a part of the ring little stressed in the ring test, i.e., near one of the elements marked (a) in Fig. 2. (See Sect. 2-18 (e).) The strips in any case will be in cross section as indicated in Fig. 1, i.e., will have for their width the thickness of the pipe and for their thickness 0.50 inch. Their length will be the length of the ring, 12 inches; or, if

not cut from a ring, at least 11 inches. These strips shall be tested as a beam on supports 10 inches apart with loads applied perpendicularly to the machined faces at two points $3\frac{1}{3}$ inches from the supports. The breaking load and the corresponding deflection shall be observed and recorded.

The strip shall be accurately calipered at point of rupture and the modulus of rupture, R, shall be calculated by the usual beam formula which for this case reduces to the expression:

$$R = \frac{10W}{td^2}$$

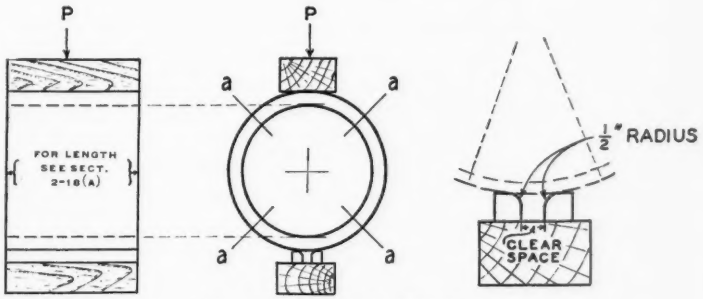


FIG. 2. Assembly for Ring Test

The secant modulus of elasticity E_s, in lb. per sq.in. shall be computed by the formula:

$$E_s = \frac{213W}{td^3y} = \frac{21.3R}{dy}$$

where R = modulus of rupture, lb. per sq.in.
E_s = secant modulus of elasticity, lb. per sq.in.
W = breaking load, lb.
d = depth of strip in inches (intended to be 0.50 in.)
t = width of strip, inches (pipe thickness)
y = deflection of strip at center at breaking load, inches.

To be acceptable a Talbot strip shall have the modulus of rupture, R, not less than 30,000 lb. per sq.in. and the secant modulus of elasticity, E_s, not more than 10,000,000 lb. per sq.in. If the results from either strip are up to the specifications the test shall be regarded as satisfactory.

(e) *Ring Tests.* Each ring shall be tested by the three-edge-bearing method as indicated in Fig. 2. The lower bearing for the

ring shall consist of two strips with vertical sides having their interior top corners rounded to a radius of approximately $\frac{1}{2}$ inch. The strips shall be of hard wood or of metal. If of metal a piece of leather belting about $\frac{3}{16}$ inch thick shall be laid over them. They shall be straight and shall be securely fastened to a rigid block with their interior vertical faces spaced at a distance apart as given in the following table:

Diam. of Pipe	Clear Space
12-inch and smaller	$\frac{1}{2}$ inch
14-inch to 24-inch inclusive	1 inch
30-inch and larger	2 inch

The upper bearing shall be a rigid wooden block, straight and true from end to end. The upper and lower bearings shall extend the full length of the outside of the ring. The ring shall be placed symmetrically between the two bearings, and the center of application of the load shall be so placed that the vertical deformations at the two ends of the ring shall be equal. If the ring is not uniform in thickness, it shall be so placed that the thick and thin portions are near the ends of the horizontal diameter. A record of the breaking load and the corresponding vertical deformation of each ring tested shall be made. In order to be acceptable the modulus of rupture computed from the formula

$$R = 0.954 \frac{W(d + t)}{bt^2}$$

shall be not less than 31,000 lb. per sq.in., and the secant modulus of elasticity computed from the formula

$$E_s = \frac{0.225\, W(d + t)^3}{bt^3 y} = \frac{0.236\, R(d + t)^2}{ty}$$

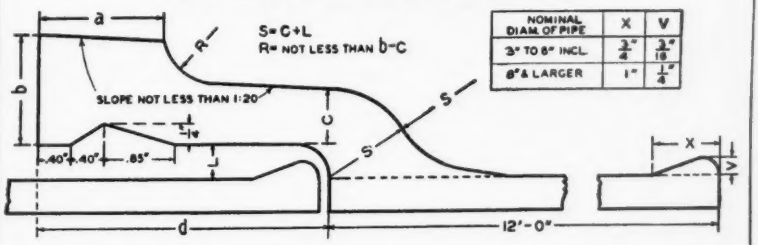
shall not exceed 15,000,000 lb. per sq.in.

b = length of ring, inches
d = average inside diameter of ring, inches
t = average thickness of metal along line of fracture, inches
y = maximum vertical deflection of ring, inches
W = breaking load, in lb.
R = modulus of rupture, lb. per sq.in.
E_s = secant modulus of elasticity, lb. per sq.in.

The modulus of elasticity shall not be determined in rings from pipe less than 12 inches in diameter.

Table No. 1

STANDARD DIMENSIONS OF BELLS, SOCKETS, SPIGOT BEADS and OUTSIDE DIAMETERS of PIT CAST PIPE also WEIGHTS OF BELLS AND OF SPIGOT BEADS



NOMINAL DIAM. OF PIPE	X	V
3" TO 6" INCL.	3/4"	3/16"
8" & LARGER	1"	1/4"

Nominal Diam.	Thickness of pipe		Out-Side Diam. of Pipe	DIMENSIONS OF BELLS						Wt. of Bell	Wt. of Spigot Bead
	From	To		Diam. of Socket	Thickness of Joint L	Depth of Socket d	a	b	c		
3	.37	.45	3.80	4.60	.40	3.50	1.25	1.30	.65	19	.3
	.46	.53	3.96	4.76	.40	3.50	1.25	1.30	.65	20	.3
4	.40	.45	4.80	5.60	.40	3.50	1.50	1.30	.65	23	.3
	.46	.55	5.00	5.80	.40	3.50	1.50	1.30	.65	24	.4
6	.43	.50	6.90	7.70	.40	3.50	1.50	1.40	.70	33	.5
	.51	.60	7.10	7.90	.40	3.50	1.50	1.40	.70	34	.5
	.61	.66	7.22	8.02	.40	4.00	1.50	1.75	.75	56	.9
	.67	.74	7.38	8.18	.40	4.00	1.50	1.85	.85	62	.9
8	.46	.57	9.05	9.85	.40	4.00	1.50	1.50	.75	48	1.1
	.58	.70	9.30	10.10	.40	4.00	1.50	1.50	.75	49	1.2
	.71	.76	9.42	10.22	.40	4.00	1.50	1.85	.85	75	1.2
	.77	.85	9.60	10.40	.40	4.00	1.50	1.95	.95	84	1.2
10	.50	.60	11.10	11.90	.40	4.00	1.50	1.50	.75	58	1.4
	.61	.75	11.40	12.20	.40	4.00	1.50	1.60	.80	64	1.4
	.76	.85	11.60	12.40	.40	4.50	1.75	1.95	.95	99	1.4
	.86	.97	11.84	12.64	.40	4.50	1.75	2.05	1.05	110	1.5
12	.54	.65	13.20	14.00	.40	4.00	1.50	1.60	.80	72	1.6
	.66	.80	13.50	14.30	.40	4.00	1.50	1.70	.85	78	1.7
	.81	.94	13.78	14.58	.40	4.50	1.75	2.05	1.05	125	1.7
	.95	1.09	14.08	14.88	.40	4.50	1.75	2.20	1.20	144	1.7
14	.54	.62	15.30	16.10	.40	4.00	1.50	1.70	.85	88	1.9
	.63	.87	15.65	16.45	.40	4.00	1.50	1.80	.90	96	1.9
	.88	1.04	15.98	16.78	.40	4.50	2.00	2.15	1.15	148	2.0
	1.05	1.21	16.32	17.12	.40	4.50	2.00	2.35	1.35	183	2.0
16	.58	.67	17.40	18.40	.50	4.00	1.75	1.80	.90	114	2.1
	.68	.95	17.80	18.80	.50	4.00	1.75	1.90	1.00	128	2.2
	.96	1.13	18.16	18.96	.40	4.50	2.00	2.30	1.25	180	2.2
	1.14	1.32	18.54	19.34	.40	4.50	2.00	2.55	1.45	224	2.3
18	.63	.72	19.50	20.50	.50	4.00	1.75	1.90	.95	133	2.4
	.73	1.01	19.92	20.92	.50	4.00	1.75	2.10	1.05	154	2.4
	1.02	1.22	20.34	21.14	.40	4.50	2.25	2.45	1.40	222	2.5
	1.23	1.44	20.78	21.58	.40	4.50	2.25	2.75	1.65	283	2.5

All dimensions given in inches. All weights given in pounds.

Table No. 1 (continued)

STANDARD DIMENSIONS OF BELLS, SOCKETS, SPIGOT BEADS and OUTSIDE DIAMETERS of PIT CAST PIPE also WEIGHTS OF BELLS AND OF SPIGOT BEADS

Nominal Diam.	Thickness of pipe		Out-Side Diam. of Pipe	DIMENSIONS OF BELLS						Wt. of Bell	Wt. of Spigot Bead
	From	To		Diam. of Socket	Thickness of Joint L	Depth of Socket d	a	b	c		
20	.66	.82	21.60	22.60	.50	4.00	1.75	2.00	1.00	156	2.6
	.83	1.08	22.06	23.06	.50	4.00	1.75	2.30	1.15	189	2.7
	1.09	1.32	22.54	23.34	.40	4.50	2.25	2.55	1.50	260	2.8
	1.33	1.56	23.02	23.82	.40	4.50	2.25	2.85	1.75	326	2.8
24	.74	.92	25.80	26.80	.50	4.00	2.00	2.10	1.05	199	3.2
	.93	1.21	26.32	27.32	.50	4.00	2.00	2.50	1.25	250	3.2
	1.22	1.50	26.90	27.90	.50	5.00	2.25	2.75	1.70	349	3.3
	1.51	1.93	27.76	28.56	.40	5.00	2.25	3.15	1.95	489	3.4
30	.87	.92	31.74	32.74	.50	4.50	2.00	2.30	1.15	296	3.9
	.93	1.05	32.00	33.00	.50	4.50	2.00	2.30	1.15	298	3.9
	1.06	1.18	32.40	33.40	.50	4.50	2.00	2.60	1.32	351	4.0
	1.19	1.42	32.74	33.74	.50	4.50	2.00	3.00	1.50	416	4.0
	1.43	1.60	33.10	34.10	.50	5.00	2.25	3.25	1.80	557	4.0
	1.61	1.78	33.46	34.46	.50	5.00	2.25	3.50	2.00	626	4.1
36	.97	1.03	37.96	38.96	.50	4.50	2.00	2.50	1.25	383	4.6
	1.04	1.20	38.30	39.30	.50	4.50	2.00	2.80	1.40	446	4.7
	1.21	1.40	38.70	39.70	.50	4.50	2.00	3.10	1.60	512	4.7
	1.41	1.63	39.16	40.16	.50	4.50	2.00	3.40	1.80	586	4.8
	1.64	1.85	39.60	40.60	.50	5.00	2.25	3.70	2.05	770	4.8
	1.86	2.07	40.04	41.04	.50	5.00	2.25	4.00	2.30	876	4.9
42	1.07	1.15	44.20	45.20	.50	5.00	2.00	2.80	1.40	539	5.4
	1.16	1.30	44.50	45.50	.50	5.00	2.00	3.00	1.50	586	5.4
	1.31	1.57	45.10	46.10	.50	5.00	2.00	3.40	1.75	701	5.5
	1.58	1.84	45.58	46.58	.50	5.00	2.00	3.80	1.95	805	5.8
48	1.18	1.30	50.50	51.50	.50	5.00	2.00	3.00	1.50	660	6.1
	1.31	1.45	50.80	51.80	.50	5.00	2.00	3.30	1.65	745	6.2
	1.46	1.72	51.40	52.40	.50	5.00	2.00	3.80	1.95	900	6.2
	1.73	2.04	51.98	52.98	.50	5.00	2.00	4.20	2.20	1046	6.3
54	1.30	1.38	56.66	57.66	.50	5.50	2.25	3.20	1.60	855	6.9
	1.39	1.60	57.10	58.10	.50	5.50	2.25	3.60	1.80	993	6.9
	1.61	1.89	57.80	58.80	.50	5.50	2.25	4.00	2.15	1189	7.0
	1.90	2.25	58.40	59.40	.50	5.50	2.25	4.40	2.45	1391	7.1
60	1.39	1.45	62.80	63.80	.50	5.50	2.25	3.40	1.70	1021	7.6
	1.46	1.75	63.40	64.40	.50	5.50	2.25	3.70	1.90	1145	7.7
	1.76	2.15	64.20	65.20	.50	5.50	2.25	4.20	2.25	1393	7.8
	2.16	2.46	64.82	65.82	.50	5.50	2.25	4.70	2.60	1647	7.9

All dimensions given in inches. All weights given in pounds.

NOTE: Pipe for pressures greater than 200 pounds per square inch may be supplied with double lead groove if desired.

Table 2

STANDARD THICKNESSES, DIAMETERS AND WEIGHTS OF PIT CAST PIPE

Dimensions in Inches — Weights in Pounds

Nominal Diam.	Thickness Class	Thickness	Outside Diam.	Inside Diam.	Wt. of Barrel Per Ft.	Wt. of Bell	Wt. Based on 12 Ft. Length*	
							Per Length	Avg. Per Foot
1	2	3	4	5	6	7	8	9
3	1	.37	3.80	3.06	12.4	19	170	14.2
	2	.40	3.80	3.00	13.3	19	180	15.0
	3	.43	3.80	2.94	14.2	19	190	15.8
	4	.46	3.96	3.04	15.8	20	210	17.5
	5	.50	3.96	2.96	17.0	20	225	18.8
4	1	.40	4.80	4.00	17.3	23	230	19.2
	2	.43	4.80	3.94	18.4	23	245	20.4
	3	.46	5.00	4.08	20.5	24	270	22.5
	4	.50	5.00	4.00	22.1	24	290	24.2
	5	.54	5.00	3.92	23.6	24	310	25.8
6	1	.43	6.90	6.04	27.3	33	360	30.0
	2	.46	6.90	5.98	29.0	33	380	31.7
	3	.50	6.90	5.90	31.4	33	410	34.2
	4	.54	7.10	6.02	34.7	34	450	37.5
	5	.58	7.10	5.94	37.1	34	480	40.0
	6	.63	7.22	5.96	40.7	56	545	45.4
	7	.68	7.38	6.02	44.7	62	600	50.0
	8	.73	7.38	5.92	47.6	62	635	52.9
8	1	.46	9.05	8.13	38.7	48	515	42.9
	2	.50	9.05	8.05	41.9	48	550	45.8
	3	.54	9.05	7.97	45.0	48	590	49.2
	4	.58	9.30	8.14	49.6	49	645	53.8
	5	.63	9.30	8.04	53.5	49	690	57.5
	6	.68	9.30	7.94	57.5	49	740	61.7
	7	.73	9.42	7.96	62.2	75	825	68.8
	8	.79	9.60	8.02	68.2	84	905	75.4
	9	.85	9.60	7.90	72.9	84	960	80.0
10	1	.50	11.10	10.10	52.0	58	685	57.1
	2	.54	11.10	10.02	55.9	58	730	60.8
	3	.58	11.10	9.94	59.8	58	775	64.6
	4	.63	11.40	10.14	66.5	64	865	72.1
	5	.68	11.40	10.04	71.5	64	925	77.1
	6	.73	11.40	9.94	76.4	64	980	81.7
	7	.79	11.60	10.02	83.7	99	1105	92.1
	8	.85	11.60	9.90	89.6	99	1175	97.9
	9	.92	11.84	10.00	98.5	110	1295	107.9
12	1	.54	13.20	12.12	67.0	72	880	73.3
	2	.58	13.20	12.04	71.8	72	935	77.9
	3	.63	13.20	11.94	77.6	72	1005	83.8
	4	.68	13.50	12.14	85.5	78	1105	92.1
	5	.73	13.50	12.04	91.4	78	1175	97.9
	6	.79	13.50	11.92	98.4	78	1260	105.0
	7	.85	13.78	12.08	107.7	125	1420	118.3
	8	.92	13.78	11.94	116.0	125	1520	126.7
	9	.99	14.08	12.10	127.0	144	1670	139.2
	10	1.07	14.08	11.94	136.4	144	1785	148.8
14	1	.54	15.30	14.22	78.1	88	1025	85.4
	2	.58	15.30	14.14	83.7	88	1095	91.3
	3	.63	15.65	14.39	92.8	96	1210	100.8
	4	.68	15.65	14.29	99.8	96	1295	107.9
	5	.73	15.65	14.19	106.8	96	1380	115.0
	6	.79	15.65	14.07	115.1	96	1480	123.3
	7	.85	15.65	13.95	123.3	96	1580	131.7
	8	.92	15.98	14.14	135.8	148	1780	148.3
	9	.99	15.98	14.00	145.5	148	1895	157.9

*Including Bell and Spigot Bead. Calculated weight of Pipe rounded off to nearest 5 pounds.

Table 2 (continued)

STANDARD THICKNESSES, DIAMETERS AND WEIGHTS OF PIT CAST PIPE

Dimensions in Inches — Weights in Pounds

Nominal Diam.	Thickness Class	Thickness	Outside Diam.	Inside Diam.	Wt. of Barrel Per Ft.	Wt. of Bell	Wt. Based on 12 Ft. Length*	
							Per Length	Avg. Per Foot
1	2	3	4	5	6	7	8	9
14	10	1.07	16.32	14.18	160.0	183	2105	175.4
	11	1.16	16.32	14.00	172.4	183	2255	187.9
16	1	.58	17.40	16.24	95.6	114	1265	105.4
	2	.63	17.40	16.14	103.6	114	1360	113.3
	3	.68	17.80	16.44	114.1	128	1500	125.0
	4	.73	17.80	16.34	122.1	128	1595	132.9
	5	.79	17.80	16.22	131.7	128	1710	142.5
	6	.85	17.80	16.10	141.2	128	1825	152.1
	7	.92	17.80	15.96	152.2	128	1955	162.9
	8	.99	18.16	16.18	166.6	180	2180	181.7
	9	1.07	18.16	16.02	179.2	180	2335	194.6
	10	1.16	18.54	16.22	197.6	224	2600	216.7
	11	1.25	18.54	16.04	211.8	224	2770	230.8
18	1	.63	19.50	18.24	116.5	133	1535	127.9
	2	.68	19.50	18.14	125.4	133	1640	136.7
	3	.73	19.92	18.46	137.3	154	1805	150.4
	4	.79	19.92	18.34	148.1	154	1935	161.3
	5	.85	19.92	18 22	158.9	154	2065	172.1
	6	.92	19.92	18.08	171.3	154	2210	184.2
	7	.99	19.92	17.94	183.7	154	2360	196.7
	8	1.07	20.34	18.20	202.1	222	2650	220.8
	9	1.16	20.34	18.02	218.1	222	2840	236.7
	10	1.25	20.78	18.28	239.3	283	3155	262.9
	11	1.35	20.78	18.08	257.1	283	3370	280.8
20	1	.66	21.60	20.28	135.5	156	1785	148.8
	2	.71	21.60	20.18	145.4	156	1905	158.8
	3	.77	21.60	20.06	157.2	156	2045	170.4
	4	.83	22.06	20.40	172.7	189	2265	188.8
	5	.90	22.06	20.26	186.7	189	2430	202.5
	6	.97	22.06	20.12	200.5	189	2600	216.7
	7	1.05	22.06	19.96	216.2	189	2785	232.1
	8	1.13	22.54	20.28	237.1	260	3110	259.2
	9	1.22	22.54	20.10	255.0	260	3325	277.1
	10	1.32	22.54	19.90	274.6	260	3560	296.7
	11	1.43	23.02	20.16	302.6	326	3960	330.0
24	1	.74	25.80	24.32	181.8	199	2385	198.8
	2	.80	25.80	24.20	196.0	199	2555	212.9
	3	.86	25.80	24.08	210.2	199	2725	227.1
	4	.93	26.32	24.46	231.5	250	3030	252.5
	5	1.00	26.32	24.32	248.2	250	3230	269.2
	6	1.08	26.32	24.16	267.2	250	3460	288.3
	7	1.17	26.32	23.98	288.4	250	3715	309.6
	8	1.26	26.90	24.38	316.7	349	4155	346.2
	9	1.36	26.90	24.18	340.5	349	4440	370.0
	10	1.47	26.90	23.96	366.4	349	4750	395.8
	11	1.59	27.76	24.58	407.9	489	5385	448.8
	12	1.72	27.76	24.32	439.0	489	5760	480.0
	13	1.86	27.76	24.04	472.2	489	6160	513.3
30	1	.87	31.74	30.00	263.3	296	3460	288.3
	2	.94	32.00	30.12	286.2	298	3735	311.3
	3	1.02	32.00	29.96	309.7	298	4020	335.0
	4	1.10	32.40	30.20	337.5	351	4405	367.1
	5	1.19	32.74	30.36	368.0	416	4835	402.9
	6	1.29	32.74	30.16	397.7	416	5190	432.5
	7	1.39	32.74	29.96	427.1	416	5545	462.1

*Including Bell and Spigot Bead. Calculated weight of Pipe rounded off to nearest 5 pounds.

Table 2 (continued)

STANDARD THICKNESSES, DIAMETERS AND WEIGHTS OF PIT CAST PIPE

Dimensions in Inches — Weights in Pounds

Nominal Diam.	Thickness Class	Thickness	Outside Diam.	Inside Diam.	Wt. of Barrel Per Ft.	Wt. of Bell	Wt. Based on 12 Ft. Length*	
							Per Length	Avg. Per Foot
1	2	3	4	5	6	7	8	9
30	8	1.50	33.10	30.10	464.6	557	6135	511.3
	9	1.62	33.46	30.22	505.6	626	6695	557.9
	10	1.75	33.46	29.96	543.9	626	7155	596.3
36	1	.97	37.96	36.02	351.7	383	4610	384.2
	2	1.05	38.30	36.20	383.4	446	5050	420.8
	3	1.13	38.30	36.04	411.7	446	5390	449.2
	4	1.22	38.70	36.26	448.2	512	5895	491.3
	5	1.32	38.70	36.06	483.6	512	6320	526.7
	6	1.43	39.16	36.30	528.9	586	6940	578.3
	7	1.54	39.16	36.08	567.9	586	7405	617.1
	8	1.66	39.60	36.28	617.3	770	8180	681.7
	9	1.79	39.60	36.02	663.4	770	8735	727.9
	10	1.93	40.04	36.18	720.9	876	9530	794.2
42	1	1.07	44.20	42.06	452.3	539	5970	497.5
	2	1.16	44.50	42.18	492.8	586	6505	542.1
	3	1.25	44.50	42.00	529.9	586	6950	579.2
	4	1.35	45.10	42.40	578.9	701	7655	637.9
	5	1.46	45.10	42.18	624.5	701	8200	683.3
	6	1.58	45.58	42.42	681.4	805	8990	749.2
	7	1.71	45.58	42.16	735.3	805	9635	802.9
48	1	1.18	50.50	48.14	570.4	660	7510	625.8
	2	1.27	50.50	47.96	612.8	660	8020	668.3
	3	1.37	50.80	48.06	663.8	745	8715	726.3
	4	1.48	51.40	48.44	724.2	900	9595	799.6
	5	1.60	51.40	48.20	781.0	900	10280	856.7
	6	1.73	51.98	48.52	852.1	1046	11280	940.0
	7	1.87	51.98	48.24	918.5	1046	12075	1006.3
	8	2.02	51.98	47.94	989.2	1046	12925	1077.1
54	1	1.30	56.66	54.06	705.4	855	9325	777.1
	2	1.40	57.10	54.30	764.3	993	10170	847.5
	3	1.51	57.10	54.08	822.8	993	10875	906.3
	4	1.63	57.80	54.54	897.4	1189	11965	997.1
	5	1.76	57.80	54.28	966.8	1189	12800	1066.7
	6	1.90	58.40	54.60	1052.2	1391	14025	1168.8
	7	2.05	58.40	54.30	1132.3	1391	14985	1248.8
	8	2.21	58.40	53.98	1217.2	1391	16005	1333.8
60	1	1.39	62.80	60.02	836.7	1021	11070	922.5
	2	1.50	63.40	60.40	910.1	1145	12075	1006.3
	3	1.62	63.40	60.16	981.0	1145	12925	1077.1
	4	1.75	63.40	59.90	1057.5	1145	13845	1153.8
	5	1.89	64.20	60.42	1154.3	1393	15250	1270.9
	6	2.04	64.20	60.12	1242.9	1393	16315	1359.6
	7	2.20	64.82	60.42	1350.3	1647	17860	1488.3
	8	2.38	64.82	60.06	1456.6	1647	19135	1594.6

NOTE: When pipe is to be cement lined, patterns and cores giving larger outside and inside diameter without change of thickness will be used if ordered.

*Including Bell and Spigot Bead. Calculated weight of Pipe rounded off to nearest 5 pounds.

Table No. 3

STANDARD THICKNESSES AND WEIGHTS OF CAST IRON PIT CAST PIPE

NOTE: These weights are for pipe laid without blocks, on flat bottom trench, with tamped backfill, under 5 feet of cover. For other conditions see Table 4 hereof and the Manual.

Size Inches	CLASS 50 50 Lb. Pressure 115 Feet Head			CLASS 100 100 Lb. Pressure 231 Feet Head			CLASS 150 150 Lb. Pressure 346 Feet Head			CLASS 200 200 Lb. Pressure 462 Feet Head		
		Wt Based on 12 Ft. Lgh.*			Wt. Based on 12 Ft. Lgh.*			Wt. Based on 12 Ft. Lgh.*			Wt. Based on 12 Ft. Lgh.*	
	Thickness Inches	Avg. Per Foot	Per Length	Thickness Inches	Avg. Per Foot	Per Length	Thickness Inches	Avg. Per Foot	Per Length	Thickness Inches	Avg. Per Foot	Per Length
3	.37	14.2	170	.37	14.2	170	.37	14.2	170	.37	14.2	170
4	.40	19.2	230	.40	19.2	230	.40	19.2	230	.40	19.2	230
6	.43	30.0	360	.43	30.0	360	.43	30.0	360	.43	30.0	360
8	.46	42.9	515	.46	42.9	515	.46	42.9	515	.46	42.9	515
10	.50	57.1	685	.50	57.1	685	.54	60.8	730	.58	64.6	775
12	.54	73.3	880	.54	73.3	880	.58	77.9	935	.63	83.8	1005
14	.54	85.4	1025	.58	91.3	1095	.63	100.8	1210	.68	107.9	1295
16	.58	105.4	1265	.63	113.3	1360	.68	125.0	1500	.79	142.5	1710
18	.63	127.9	1535	.68	136.7	1640	.73	150.4	1805	.85	172.1	2065
20	.66	148.8	1785	.71	158.8	1905	.83	188.8	2265	.90	202.5	2430
24	.74	198.8	2385	.80	212.9	2555	.93	252.5	3030	1.00	269.2	3230
30	.87	288.3	3460	.94	311.3	3735	1.10	367.1	4405	1.19	402.9	4835
36	.97	384.2	4610	1.05	420.8	5050	1.22	491.3	5895	1.43	578.3	6940
42	1.07	497.5	5970	1.25	579.2	6950	1.35	637.9	7655	1.58	749.2	8990
48	1.18	625.8	7510	1.37	726.3	8715	1.48	799.6	9595	1.73	940.0	11280
54	1.30	777.1	9325	1.51	906.3	10875	1.63	997.1	11965	1.90	1168.8	14025
60	1.39	922.5	11070	1.62	1077.1	12925	1.89	1270.9	15250	2.20	1488.3	17860

*Including Bell and Spigot Bead. Calculated weight of Pipe rounded off to nearest 5 pounds.

Table No. 3 (Continued)

STANDARD THICKNESSES AND WEIGHTS OF CAST IRON PIT CAST PIPE

NOTE: These weights are for pipe laid without blocks, on flat bottom trench, with tamped backfill, under 5 feet of cover. For other conditions see Table 4 hereof and the Manual.

	CLASS 250			CLASS 300			CLASS 350		
	250 Lb. Pressure			300 Lb. Pressure			350 Lb. Pressure		
	577 Feet Head			693 Feet Head			808 Feet Head		
		Wt. Based on 12 Ft. Lgh.*			Wt. Based on 12 Ft. Lgh.*			Wt. Based on 12 Ft. Lgh.*	
Size Inches	Thickness Inches	Avg. Per Foot	Per Length	Thickness Inches	Avg. Per Foot	Per Length	Thickness Inches	Avg. Per Foot	Per Length
3	.37	14.2	170	.37	14.2	170	.37	14.2	170
4	.40	19.2	230	.40	19.2	230	.40	19.2	230
6	.43	30.0	360	.46	31.7	380	.50	34.2	410
8	.50	45.8	550	.54	49.2	590	.58	53.8	645
10	.63	72.1	865	.68	77.1	925	.73	81.7	980
12	.68	92.1	1105	.73	97.9	1175	.79	105.0	1260
14	.79	123.3	1480	.85	131.7	1580	.92	148.3	1780
16	.85	152.1	1825	.92	162.9	1955	.99	181.7	2180
18	.92	184.2	2210	.99	196.7	2360	1.07	220.8	2650
20	.97	216.7	2600	1.05	232.1	2785	1.22	277.1	3325
24	1.08	288.3	3460	1.26	346.2	4155	1.36	370.0	4440
30	1.39	462.1	5545	1.50	511.3	6135	1.62	557.9	6695
36	1.54	617.1	7405	1.79	727.9	8735	1.93	794.2	9530
42	1.71	802.9	9635						
48	2.02	1077.1	12925						
54	2.21	1333.8	16005						
60	2.38	1594.6	19135						

*Including Bell and Spigot Bead. Calculated weight of Pipe rounded off to nearest 5 pounds.

Table No. 4

STANDARD THICKNESSES OF CAST IRON PIT CAST PIPE

Thickness in Inches. Working Pressure in Pounds per Square Inch.
Thicknesses Include Allowances for Water Hammer,
Foundry Practice and Corrosion

Laying Condition A—Flat Bottom Trench, Without Blocks, Untamped Backfill
Laying Condition B—Flat Bottom Trench, Without Blocks, Tamped Backfill
Laying Condition C—Pipe Laid on Blocks, Untamped Backfill
Laying Condition D—Pipe Laid on Blocks, Tamped Backfill

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
3	50	.37	.37	.37	.37	.37	.37	.37	.37	.37	.37	.43	.37
	100	.37	.37	.37	.37	.37	.37	.37	.37	.37	.37	.43	.37
	150	.37	.37	.37	.37	.37	.37	.40	.37	.37	.37	.43	.37
	200	.37	.37	.37	.37	.37	.37	.40	.37	.37	.37	.43	.37
	250	.37	.37	.37	.37	.37	.37	.40	.37	.37	.37	.46	.37
	300	.37	.37	.37	.37	.37	.37	.40	.37	.37	.37	.46	.37
	350	.37	.37	.40	.37	.37	.37	.40	.37	.37	.37	.46	.37
4	50	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
	100	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
	150	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
	200	.40	.40	.43	.40	.40	.40	.43	.40	.40	.40	.50	.40
	250	.40	.40	.43	.40	.40	.40	.46	.40	.40	.40	.50	.40
	300	.40	.40	.43	.40	.40	.40	.46	.40	.40	.40	.54	.40
	350	.40	.40	.46	.40	.40	.40	.46	.40	.40	.40	.54	.40
6	50	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.58	.43
	100	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.58	.43
	150	.43	.43	.50	.43	.43	.43	.50	.43	.43	.43	.58	.43
	200	.43	.43	.50	.43	.43	.43	.54	.43	.43	.43	.58	.43
	250	.43	.43	.50	.43	.43	.43	.54	.43	.46	.46	.63	.46
	300	.46	.43	.54	.43	.46	.46	.54	.46	.50	.46	.63	.46
	350	.50	.50	.54	.46	.50	.50	.58	.50	.50	.50	.63	.50
8	50	.46	.46	.54	.46	.46	.46	.54	.46	.46	.46	.63	.46
	100	.46	.46	.54	.46	.46	.46	.54	.46	.46	.46	.63	.50
	150	.46	.46	.58	.46	.46	.46	.58	.46	.50	.50	.68	.50
	200	.46	.46	.58	.50	.50	.46	.58	.50	.54	.50	.68	.54
	250	.50	.50	.63	.50	.54	.50	.63	.54	.54	.54	.68	.58
	300	.54	.54	.63	.54	.58	.54	.63	.58	.58	.58	.73	.58
	350	.58	.58	.63	.58	.58	.58	.68	.58	.63	.63	.73	.63
10	50	.50	.50	.58	.50	.50	.50	.58	.50	.54	.50	.68	.54
	100	.50	.50	.58	.50	.50	.50	.63	.50	.58	.54	.73	.58
	150	.50	.50	.58	.50	.54	.54	.63	.54	.58	.58	.73	.58
	200	.54	.54	.63	.54	.58	.58	.68	.58	.63	.58	.79	.63
	250	.58	.58	.63	.58	.63	.63	.68	.63	.68	.63	.79	.68
	300	.63	.63	.68	.63	.68	.68	.73	.68	.68	.68	.79	.73
	350	.68	.68	.73	.68	.73	.73	.79	.73	.73	.73	.85	.73
12	50	.54	.54	.58	.54	.54	.54	.63	.54	.58	.58	.73	.63
	100	.54	.54	.63	.54	.54	.54	.63	.58	.63	.58	.79	.63
	150	.58	.54	.63	.58	.58	.58	.68	.63	.68	.63	.79	.68
	200	.63	.58	.68	.63	.63	.63	.73	.68	.68	.68	.85	.73
	250	.68	.68	.73	.68	.68	.68	.79	.73	.73	.73	.85	.73
	300	.73	.73	.79	.73	.73	.73	.79	.79	.79	.79	.92	.79
	350	.79	.79	.85	.79	.79	.79	.85	.85	.85	.85	.92	.85
14	50	.54	.54	.63	.58	.58	.54	.68	.58	.68	.63	.79	.68
	100	.58	.54	.68	.58	.63	.58	.73	.63	.68	.68	.85	.73
	150	.63	.63	.68	.63	.68	.63	.73	.68	.73	.73	.85	.79
	200	.68	.68	.73	.68	.73	.68	.79	.73	.79	.79	.92	.79
	250	.79	.73	.79	.79	.79	.79	.85	.79	.85	.79	.92	.85
	300	.85	.85	.85	.85	.85	.85	.92	.85	.92	.85	.99	.92
	350	.92	.92	.92	.92	.92	.92	.99	.92	.99	.92	1.07	.99

Table No. 4—Continued

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
16	50	.58	.58	.68	.63	.63	.58	.73	.63	.73	.68	.85	.73
	100	.63	.58	.73	.63	.68	.63	.73	.68	.73	.73	.85	.79
	150	.68	.68	.73	.68	.73	.68	.79	.73	.79	.79	.92	.85
	200	.73	.73	.79	.73	.79	.79	.85	.79	.85	.79	.92	.85
	250	.79	.79	.85	.85	.85	.85	.92	.85	.92	.85	.99	.92
	300	.92	.92	.92	.92	.92	.92	.99	.92	.99	.92	1.07	.99
	350	.99	.99	.99	.99	.99	.99	1.07	.99	1.07	.99	1.16	1.07
18	50	.63	.63	.73	.68	.68	.63	.79	.68	.79	.73	.85	.79
	100	.68	.63	.73	.68	.73	.68	.79	.73	.85	.79	.92	.85
	150	.73	.73	.79	.73	.79	.73	.85	.79	.85	.85	.99	.92
	200	.79	.79	.85	.85	.85	.85	.92	.85	.92	.85	.99	.99
	250	.92	.92	.92	.92	.92	.92	.99	.92	.99	.99	1.07	.99
	300	.99	.99	.99	.99	.99	.99	1.07	1.07	1.07	1.07	1.16	1.07
	350	1.07	1.07	1.07	1.07	1.07	1.07	1.16	1.07	1.16	1.16	1.25	1.16
20	50	.66	.66	.77	.71	.71	.66	.83	.77	.83	.77	.90	.83
	100	.71	.66	.83	.77	.77	.71	.83	.83	.83	.83	.97	.90
	150	.77	.77	.83	.77	.83	.83	.90	.83	.90	.90	1.05	.97
	200	.83	.83	.90	.90	.90	.90	.97	.90	.97	.97	1.05	1.05
	250	.97	.97	.97	.97	.97	.97	1.05	1.05	1.05	1.05	1.13	1.13
	300	1.05	1.05	1.05	1.05	1.13	1.05	1.13	1.13	1.13	1.13	1.22	1.13
	350	1.22	1.13	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.32	1.22
24	50	.74	74	.86	.80	.80	.74	.86	.86	.93	.86	1.00	.93
	100	.80	.74	.86	.86	.86	.80	.93	.93	1.00	.93	1.08	1.00
	150	.86	.86	.93	.86	.93	.93	1.00	1.00	1.08	1.00	1.08	1.08
	200	1.00	1.00	1.00	1.00	1.08	1.00	1.08	1.08	1.17	1.08	1.17	1.17
	250	1.08	1.08	1.17	1.08	1.17	1.08	1.17	1.17	1.26	1.17	1.26	1.26
	300	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.36	1.26	1.36	1.36
	350	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.47	1.36	1.47	1.47
30	50	.94	.87	1.02	.94	.94	.87	1.02	.94	1.10	1.02	1.19	1.10
	100	.94	.87	1.02	.94	1.02	.94	1.10	1.02	1.19	1.10	1.29	1.19
	150	1.10	1.02	1.10	1.10	1.19	1.10	1.19	1.19	1.29	1.19	1.39	1.29
	200	1.19	1.19	1.19	1.19	1.29	1.19	1.29	1.29	1.39	1.29	1.39	1.39
	250	1.29	1.29	1.39	1.39	1.39	1.39	1.50	1.39	1.50	1.39	1.50	1.50
	300	1.50	1.50	1.50	1.50	1.50	1.50	1.62	1.50	1.62	1.50	1.62	1.62
	350	1.62	1.62	1.62	1.62	1.62	1.62	1.75	1.62	1.75	1.75	1.75	1.75
36	50	1.05	.97	1.13	1.05	1.05	.97	1.22	1.05	1.22	1.13	1.32	1.22
	100	1.13	.97	1.22	1.13	1.22	1.05	1.22	1.13	1.32	1.22	1.43	1.32
	150	1.22	1.13	1.22	1.22	1.32	1.22	1.32	1.32	1.43	1.32	1.54	1.43
	200	1.32	1.32	1.43	1.32	1.43	1.43	1.43	1.43	1.54	1.43	1.66	1.54
	250	1.54	1.54	1.54	1.54	1.66	1.54	1.66	1.66	1.66	1.66	1.79	1.66
	300	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.93	1.79
	350	1.93	1.93	1.93	1.93	1.93	1.93	2.08	1.93	2.08	1.93	2.08	2.08
42	50	1.16	1.07	1.25	1.16	1.25	1.07	1.35	1.25	1.35	1.25	1.46	1.35
	100	1.25	1.07	1.35	1.25	1.35	1.25	1.35	1.35	1.46	1.35	1.58	1.46
	150	1.35	1.25	1.46	1.35	1.46	1.35	1.46	1.46	1.58	1.46	1.71	1.58
	200	1.58	1.46	1.58	1.58	1.58	1.58	1.71	1.58	1.71	1.58	1.85	1.71
	250	1.71	1.71	1.85	1.71	1.85	1.71	1.85	1.85	1.85	1.85	2.00	1.85
48	50	1 27	1.18	1.37	1.27	1.37	1.18	1.48	1.37	1.60	1.37	1.60	1.48
	100	1.37	1.27	1.48	1.37	1.48	1.37	1.60	1.48	1.73	1.48	1.73	1.60
	150	1.48	1.48	1.60	1.48	1.60	1.48	1.73	1.60	1.87	1.60	1.87	1.73
	200	1.73	1.73	1.73	1.73	1.87	1.73	1.87	1.87	2.02	1.87	2.02	1.87
	250	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.18	2.02	2.18	2.18
54	50	1.40	1.30	1.51	1.40	1.51	1.30	1.63	1.40	1.63	1.51	1.76	1.63
	100	1.51	1.40	1.63	1.51	1.63	1.51	1.76	1.63	1.90	1.63	1.90	1.76
	150	1.63	1.63	1.76	1.63	1.76	1.63	1.90	1.76	2.05	1.76	2.05	1.90
	200	1.90	1.90	2.05	1.90	2.05	1.90	2.05	2.05	2.21	2.05	2.21	2.21
	250	2.21	2.21	2.21	2.21	2.21	2.21	2.39	2.21	2.39	2.21	2.39	2.39
60	50	1.50	1.39	1.62	1.50	1.62	1.39	1.75	1.50	1.89	1.62	1.89	1.75
	100	1.62	1.50	1.75	1.62	1.75	1.62	1.89	1.75	2.04	1.75	2.04	1.89
	150	1.89	1.75	1.89	1.75	2.04	1.89	2.04	1.89	2.20	2.04	2.20	2.04
	200	2.04	2.04	2.20	2.04	2.20	2.20	2.20	2.20	2.38	2.20	2.38	2.38
	250	2.38	2.38	2.38	2.38	2.57	2.38	2.57	2.57	2.57	2.57	2.78	2.57

ASA
A21.4-1939

American Standard

SPECIFICATIONS

for

CEMENT MORTAR LINING FOR CAST IRON PIPE AND FITTINGS

Approved by
American Standards Association
December, 1939

SPONSORS

American Gas Association
American Society for Testing Materials
American Water Works Association
New England Water Works Association

AMERICAN ENGINEERING AND INDUSTRIAL STANDARDS

Approved by New England Water Works Association September 12, 1939

FOREWORD

This specification provides alternative procedures in the case of certain details with respect to which practice is not standardized. The purchaser, when inviting bids, should specify his requirements, if any, with respect to the following details which, unless so specified, will be at the option of the manufacturer:

Sect. 4–10. Whether linings shall have tapered ends or be of full thickness to the ends.

Sect. 4–14. Whether coal-tar outside coating is required. If required, and unless a hot-coal-tar-dip coating is specified, the manufacturer has the option of applying either the specification hot-coal-tar-dip coating or two coats of the specification coal-tar paint.

Sect 4–15. Whether whitewash outside coating is required, and for pipes of what diameters. If not specified the manufacturer has the option of whitewashing or not at his discretion.

Sect. 4–16. Whether bituminous seal coat is required.

AMERICAN STANDARD SPECIFICATIONS
for
CEMENT MORTAR LINING
FOR CAST IRON PIPE AND FITTINGS

Sect. 4-1. Portland Cement

Portland cement shall meet all the requirements of Standard Specifications for Portland Cement of the American Society for Testing Materials, A.S.T.M. Designation: C 9, of latest revision.

Sect. 4-2. Sand

Sand shall consist of hard, strong, durable, uncoated, silicious particles. Under the colorimetric test for organic impurities it shall not produce a color darker than the standard, unless it is shown by adequate tests that the impurities causing the color are not harmful to the strength or other specified properties of the finished lining. It shall lose not more than 3 per cent in the decantation test, not more than 1 per cent on ignition, and not more than 4 per cent in boiling hydrochloric acid. The sand shall be well graded so as to produce a lining as nearly as practicable of maximum density and minimum water absorption consistent with the proportion of cement and the lining methods used, with workability of the mortar and with the other specified properties of the lining; provided that, when tested with standard sieves, it shall meet the following requirements: (1)*

	Per cent
Total passing sieve having a clear opening of the size nearest to one-half the specified minimum thickness of lining	100
Passing No. 100 sieve, not more than	5

* Numbers in parenthesis such as that above refer to notes following this standard.

Sect. 4-3. Accepted Specifications

The specified tests of sand shall be made in accordance with the Standard Methods of the American Society for Testing Materials, and of the American Foundrymen's Association, of latest revision, as follows:

Colorimetric Test: Standard Method of Test for Organic Impurities in Sands for Concrete, A.S.T.M. Designation C40.

Standard Method of Decantation Test for Sand and other Fine Aggregates, A.S.T.M. Designation D136.

Ignition Test: Testing and Grading of Foundry Sand, American Foundrymen's Assn., 1931, p. 94, 25 gram sample, flat porcelain dish.

Solubility in hydrochloric acid—Standard Method of Testing Bituminous Mastics, Grouts, and like Mixtures, A.S.T.M. Designation D147.

Sect. 4-4. Water

Water for tempering the mortar and for curing the lining shall be potable water, as defined in Appendix I, Section 3 of the 1925 U. S. Treasury "Drinking Water Standards."

Sect. 4-5. Mortar

The mortar shall be an intimate and thorough mixture of portland cement, sand and water of the qualities specified, and shall contain no other ingredient; except that, subject to the approval of the purchaser, other hydraulic cements producing lining having lower water-solubility, less shrinkage or other advantages may be substituted for portland cement in whole or in part, other ingredients may be incorporated in the mortar, and/or the sand omitted. Portland cement mortar for linings not exceeding one-quarter inch in minimum thickness shall contain not less than one part of cement to one part of dry sand by volume. (1) (2)

Sect. 4-6. Preparation of Pipe and Fittings for Lining

All pipes and fittings shall be thoroughly cleaned and surfaces to be lined shall be free from harmful amounts of blacking, grease, dirt, loose sand, rust, slag, soda or other flux, and from tar or other coating, and shall be entirely free from sharp projections of iron which might reduce the thickness of the lining. Required hydrostatic tests shall be made before lining.

Sect. 4-7. Method of Applying Cement Mortar Linings

The waterway surfaces of pipes and fittings shall be completely covered with as nearly as practicable a uniform thickness of the specified mortar entirely free from holidays or visible bubbles of air and thoroughly compacted throughout. Straight pipes shall be lined by the centrifugal process, combining high speed spinning and vibration, or by some other process producing linings which are equal to such centrifugal linings in accuracy of surface contour, smoothness of surface texture, density, low water absorption, and freedom from shrinkage cracks and loose spots. Fittings shall be lined by such process as will produce linings equal, as nearly as practicable, in the above enumerated respects to the linings of straight pipes. Defective linings which have set shall not be patched.

Sect. 4-8. Bell to be Cleaned

All mortar shall be removed from the joint surface of the bell.

Sect. 4-9. Work to be Protected

The work of lining the pipes and fittings shall be done in a building where the product shall be protected from the direct rays of the sun, and from extreme weather conditions, such as frost, rain, etc. The product shall not be put on the yard until the cement has set sufficiently to avoid injury or damage thereto.

Sect. 4-10. Thickness of Lining

The thickness of linings for pipes and fittings shall be nowhere less than the following for the respective diameters: 4 to 12 inches, $\frac{1}{8}$ inch; 14 to 24 inches, $\frac{3}{16}$ inch; 30 to 48 inches, $\frac{1}{4}$ inch. Linings shall taper at the ends, or shall be of full thickness to the end of the spigot and to the seat of the bell, as specified. When tapered linings are furnished the length of the taper from the end of the spigot and from the seat of the bell to lining of the full specified thickness shall not exceed sixteen times the specified thickness of lining. A plus tolerance of $\frac{1}{8}$-inch, but no more, shall be permitted on all sizes of pipe and $\frac{1}{4}$-inch, but no more, on all sizes and patterns of fittings. Linings of greater thickness will be furnished when specified.

Sect. 4-11. Determination of Thickness

The thickness of lining may be determined by means of spear measurement, using a hardened steel point not larger than $\frac{1}{16}$ inch in diameter. The inspector shall pierce the lining immediately after it is placed in the pipe, and before the mortar has set, at four dia-

metrically opposite points of the pipe at bell and spigot ends, making two sets of measurements at each end. The first set shall not be more than 4 inches from the respective ends of the pipe and the second set shall be made as far into the interior of the pipe as can readily be reached without injuring the lining.

Sect. 4-12. Curing

All parts of the lining shall be kept constantly damp for at least 42 hours after the lining is placed and as much longer as may be necessary to control separation and cracking. No pipe or fittings shall be shipped until the lining is thoroughly set and hard.

Sect. 4-13. The Finished Lining

The linings of both pipes and fittings, after curing and drying shall meet the following requirements:

(a) *Surface and contour.* The lining shall have a hard, smooth surface and shall be free from noticeable ridges, corrugations, elevations and depressions. The linings of pipes shall be cylindrical; the linings of fittings shall be as nearly as practicable of uniform thickness throughout and shall afford smooth waterways.

(b) *Water absorption.* When tested for water absorption in accordance with Standard Specifications for Cement Concrete Sewer Pipe, A.S.T.M. Designation: C-14, of latest revision, the lining shall show an absorption not exceeding 17 per cent of its dry weight. Samples for this test may be from linings placed for this purpose in the bell, provided that such linings are of the same thickness and mix, placed and compacted at the same time and by the same methods, and subjected to the same curing as the linings of the waterways. Samples at time of tests shall be not more than 30 days older than the most recently placed of the linings in the shipment or order which they represent. (3)

(c) *Cracks and loose spots.* Pipe showing three or more loose spots measuring 12 inches or more in diameter, or three or more shrinkage cracks over 9 inches in length, or any cracks standing open perceptibly, shall be rejected. Surface crazing shall not be cause for rejection.

Sect. 4-14. Bituminous Outside Coatings*

Pipe and fittings for which an outside coal-tar coating is called for, shall be coated hot or cold as specified. Pipes and fittings for which a hot coal-tar coating, or coal-tar dip coating is specified shall be coated hot, before lining, on the outside only, as specified in the Proposed American Standard for Coal-Tar-Dip Coating for Cast Iron Pipe and Fittings.† Pipe and fittings for which a cold coal-tar paint or coating is specified shall receive two coats of an approved coal-tar pitch paint complying in quality and application with the paint described in the same specification. If not specified by the purchaser, the choice of a hot or cold coal-tar coating shall be at the option of the manufacturer.

Sect. 4-15. Whitewash*

Unless otherwise specified, whitewashing of the outside surfaces of cement mortar lined pipes and fittings shall be at the option of the manufacturer. If so specified all cement-mortar lined pipes and fittings either of certain sizes or of all sizes shall be coated, after lining and before being exposed to the sun, on all exterior surfaces with an opaque coat of tenacious and weather-resistant whitewash. Whitewashed surfaces which may become damaged or blackened with tar, paint, or otherwise shall be rewhitewashed before shipment.

Sect. 4-16. Bituminous Seal Coat §

When a bituminous seal coat is specified all exposed surfaces of the mortar lining shall, when sufficiently dry, and not less than 66 hours after placing the lining, be given a full coat, without pin holes, blisters or holidays, by brushing, spraying or dipping, or other suitable means, of a water proof asphalt or coal-tar paint which, after drying 48 hours, shall have no deleterious effect upon the quality, color, taste, or odor of potable water which has been standing for 48 hours in the pipe (6). The paint shall adhere tenaciously to the mortar lining at all points. The painted pipe, when tested with distilled water in accordance with Section 4–17, shall not impart to the water more than 25 parts per million of hardness, as determined by the soap test, nor more than 25 parts per million of total alkalinity nor any caustic alkalinity.

Sect. 4-17. Testing of the Sample

Except as another form of specimen and test is agreed upon by purchaser and manufacturer, the sample shall be a 6-inch length of

* See note 4.

† Not completed in December, 1939

§ See note 5.

6- or 8-inch pipe, lathe-cut at both ends. The specimen shall be cut from a pipe whose lining is of the same age and which has been lined, cured and seal-coated in all respects like the product which it represents, the seal-coat being applied 48 hours prior to the test. With this form of specimen the test shall be made by bedding the specimen on end in a shallow pan of melted paraffin, allowing the paraffin to cool, filling the pipe nearly to the top with distilled water at laboratory temperature, and covering with a glass plate on a seal of vasoline. The water shall be changed and tested after 24 hours contact on each of three successive days, and on each test shall be free from objectionable color, taste and odor, and from hardness and alkalinity in excess of the limits specified in Sect. 4–16. Determination of hardness and alkalinity shall be made by methods prescribed in Standard Methods of Water Analysis of the American Public Health Association and the American Water Works Association, most recent edition. The purchaser shall indicate in his request for bids the number of tests and test specimens required. At the purchaser's option, this test may be made by him with the water with which the pipe is to be used.

Notes

(These notes are not parts of the standard, but are given for information only.)

(1) The art of making cement-mortar linings for cast iron pipe and fittings which will show maximum smoothness and durability as well as minimum separation, cracking and water solubility is still under active development; for this reason it is the purpose of this specification to leave the manufacturers all possible latitude consistent with insuring a product which shall be of high quality for the present state of the art. Hence, the lack of more definiteness with respect to sand grading and some other features of this specification.

(2) The provision for the use of cements other than standard portland and for other modifications of the mortar, subject to the approval of the purchaser, permits taking advantage of any useful results of the current activity in the development of hydraulic cements of special properties.

(3) The water absorption of cement-mortar linings which have been exposed to the atmosphere diminishes with increasing age of the lining, hence the 30 day limit so that the sample tested shall be reasonably representative of the shipment.

(4) Whitewash is used solely to protect the pipe from the heat of the sun which tends to expand the pipe away from the lining. If other protection is desired, the coal-tar outside coating, to be followed with whitewash in accordance with Section 4–15, may be specified. If cement-mortar-lined pipes

are to be stored for a long time along the trench or in the purchaser's yard, it is recommended that the whitewash be maintained on all sides exposed to the sun. The need for whitewashing varies with the size of the pipe, the climate and probably other conditions. Pipes 16 inches in diameter and larger are more likely to need whitewashing than smaller pipes.

(5) The purchaser who is buying cement-mortar-lined pipe for use with a water that is corrosive to calcium carbonate, such as a soft water of low alkalinity and low pH, is advised either to specify a seal coat or to satisfy himself by appropriate test that the lining to be furnished will not impart objectionable hardness or alkalinity to the water, *considering the amount of circulation in the proposed pipe line and the amount of blowing off of dead ends that he is prepared to do.* The procedure of Section 4–17, omitting the seal coat and substituting for distilled water the water with which the pipe is to be used, is suggested as a convenient form of test.

Another advantage of the seal coat is in prolonging the life of the lining.

(6) The following test for tendency of a paint to impart color, taste, and odor to the water has been used: A 2″ x 3″ x 6″ block of the mortar to be used in lining the pipe is dried, painted and exposed to the air for 48 hours; it is then placed in a covered vessel with a volume of the water of the purchaser's supply equal in cubic inches, to twice the area of the block in square inches (the volume-area relation of an 8-inch pipe). After 48 hours at laboratory temperature it is tested for color, taste and odor. At the date of this specification the following paints, as made at the dates submitted, have passed this test:

No. 119 Shop Coat Black, Harry B. Davies Co., Camden, N. J.

No. 274 Asphalt Paint, H. H. Robertson Co., Pittsburgh, Pa.

No. T-799 Black Air Drying Pipe Paint, Magic City Paint & Varnish Co., Birmingham, Ala.

Gregg's Pipe Coating Enamel, The Gregg Co., 1418 Walnut St., Philadelphia, Pa.

Hunt Process, Johnson-March Corp., 52 Vanderbilt Avenue, New York, N. Y.

Sherwin-Williams Water Tank Coating No. 96, the Sherwin-Williams Co., Cleveland, Ohio.

By changing the water and testing for hardness, total and caustic alkalinity for, say, 3 successive days, and thereafter at longer intervals, an indication of the protective value of the paint may be had.

Standard
Specifications for Fire Hydrants
for
Ordinary Water Works Service

Adopted by American Water Works Association—January 17, 1940

Adopted by the New England Water Works Association—September 26, 1940

EFFECTIVE FOR PURCHASES MADE AFTER NOVEMBER 1, 1940

The New England Water Works Association has adopted and promulgates these basic "Standard Specifications for Fire Hydrants for Ordinary Water Works Service." They are based upon the best known experience and intended for use under normal conditions. They are not designed for unqualified use under all conditions and the advisability of use of the material herein specified for any installation must be subjected to review by the engineer responsible for the construction in the particular locality concerned.

(Revised—December 1940)

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Standard Specifications for Fire Hydrants
for
Ordinary Water Works Service

Section 1—Scope of Specifications

1.01 *Scope.* These specifications embrace the various types and classes of hydrants for general water-works service and cover the materials and workmanship employed in their fabrication. The setting and drainage of hydrants are not included in these specifications. For installation standards see "Standard Specifications for Laying Cast Iron Pipe," as adopted by the A. W. W. A. in 1938, or the latest revision thereof.

1.02 *Kind and Type.* The types of hydrants covered are the various forms of post hydrants with compression (opening against or with the pressure) or gate type of shut-off. High pressure, independently-gated and special hydrants are not included.

Section 2—Capacity and Size

2.01 *Capacity.* Capacity or delivery classification shall be designated according to the number of hose and pumper nozzles employed as follows: two-hose nozzle; one-pumper nozzle; one-hose and one-pumper nozzle; three-hose nozzle; two-hose and one-pumper nozzle; three-hose and one-pumper nozzle; four-hose nozzle; two-pumper nozzle, etc.

2.02 *Size.* The size of the hydrant shall be designated in terms of the minimum opening of the seat ring of the main valve and shall be stated in inches of diameter. With other than circular seat rings, the area of the seat ring opening shall equal that of a circular seat ring of equivalent size. Any diameter offered other than those enumerated shall be considered equal to the next lower size specified in this section.

The size of the hydrant (main valve opening) shall be at least four (4) inches for hydrants having two $2\frac{1}{2}$-inch nozzles; at least five (5) inches for hydrants having three $2\frac{1}{2}$-inch nozzles; and at least six (6) inches for hydrants having four $2\frac{1}{2}$-inch nozzles.

Combinations of nozzles, other than those above, are permissible,—provided that the total potential discharge capacity of such nozzle combination connected to the main valve does not exceed the maximum discharge capacity of nozzles connected to a main valve of the same size in the above list.

Thus, since it is understood that hose nozzles and pumper nozzles are not in action at the same time, one pumper nozzle may be added to any of the above hose nozzle combinations, or substituted for any one or two hose nozzles; provided that the discharge area of the pumper nozzle *either* (1) does not exceed the discharge area of the $2\frac{1}{2}$-inch hose nozzle or nozzles to which it is added or for which it is substituted *or* (2) does not exceed the discharge area of the main valve of the hydrant.

2.03 *Length.* The length of the hydrant shall be stipulated in feet (to the nearest half foot) to correspond to the depth of trench (in which it is to be installed) below the finished or established grade; or, expressed in other terms, it shall be the distance from the bottom of the connecting pipe to the ground line at the hydrant.

Section 3—Design

3.01 *Thickness of Wall of Barrel.* The thickness of the wall of the barrel shall be not less than the thickness specified for class 250 pit cast cast-iron water pipe of like diameter produced in accordance with "American Standard Specifications for Cast Iron Pit Cast Pipe for Water and Other Liquids" (ASA-A21.2-1939) and Table 3 thereof. Barrels of fractional inch diameters shall be made to the thickness of the next larger diameter listed below. The specified thicknesses thus are:

INSIDE DIAMETER OF BARREL IN INCHES	THICKNESS OF WALL IN INCHES
5	0.42[1]
6	0.43
7	0.46[1]
8	0.50
9	0.56[1]
10	0.63

Variations in thickness of walls of hydrant barrels shall not exceed those permitted for pit cast cast-iron pipe of like diameter as re-

[1] Values not in Table 3—but interpolated for purposes of these specifications.

corded in ASA Document A21.2 and Section 2-11(b) thereof, as follows:

NOMINAL DIAMETER IN INCHES INCLUSIVE	TOLERANCE, PLUS OR MINUS IN INCHES
3 to 8	0.07
10 to 24	0.08

Tolerances 0.02 inch greater than those above listed shall be permissible over areas not exceeding 8 inches in length in any direction. Such variations, if they exist, will be presumed to relate to inexact centering or buckling of the core at the time of pouring the iron and to imply a corresponding increase in thickness of the barrel at one point in the barrel to offset the decrease in thickness at the point diametrically opposite.

3.02 *Barrel Sections.* If hydrants are made in two or more sections with a flange or other joint near the ground line, the joint shall, unless otherwise specified by the purchaser, be located at least two inches above the finished grade line.

3.03 *Waterway.* Changes in shape or size of the waterway shall be accomplished by means of easy curves. The junctions of hose and pumper nozzles with the barrel shall be rounded to ample radii. Exclusive of the main valve opening, the net area of the waterway of the barrel and foot-piece at the smallest part shall be not less than 120 per cent of that of the net opening of the main valve.

3.04 *Hydrant Inlet.* The base of the hydrant, known as the foot-piece or elbow, shall have a side or bottom inlet, provided with a bell, a flange, or other type of connection as specified or approved by the purchaser for connecting the hydrant to the branch from the main. The inlet shall have a clear waterway of not less than 6 inches nominal diameter unless otherwise ordered. In a hydrant provided with bell type of connection, the bell dimensions shall conform to those shown in the most recent Standard Specifications for Cast-Iron Pipe and Special Castings as adopted by the A.W.W.A. and the N.E.W.W.A. In a hydrant provided with flange type connections, the flange dimensions shall conform to A.S.A. (125-pound) Standard (B16a—1939).

3.05 *Lugs.* When so ordered by the purchaser, lugs for harnessing the hydrant to the connecting pipe from the street main shall be provided on the bell of the elbow.

3.06 *Hose Threads.* Unless otherwise specified by the purchaser the hose threads on the hose and the pumper nozzles shall conform

to the requirements of A.S.A. Specifications (B-26-1925) for the "National (American) Standard Fire Hose Coupling Screw Thread for all connections having nominal inside diameters of $2\frac{1}{2}$, 3, $3\frac{1}{2}$ and $4\frac{1}{2}$ inches," or the latest revision thereof (See page 12).

3.07 *Joining Nozzles to Barrel.* Hose nozzles must be of composition metal and fastened into the barrel by a fine thread or by leading. If lead is used, an adequate recess shall be provided for the lead. All nozzles shall be safeguarded against blowing out or in the case of the screwed-in nozzles, a pin or other approved method shall be employed to prevent the nozzle turning or backing out.

3.08 *Nozzle Caps.* Nozzle caps shall be provided for all outlets. The threads shall conform to those of the nozzle. The cap nut shall have dimensions similar to those of the operating nut. Unless otherwise ordered caps shall be securely chained to the barrel with a metal chain having links not less than $\frac{1}{8}$ inch in diameter, or of equivalent cross sectional area. A recess shall be provided at the inner end of the threads to retain a gasket. When specified by the purchaser, each cap shall be provided with a suitable gasket to secure a tight seal with the nozzle.

3.09 *Valves Readily Removable.* The hydrant shall be so designed that when in place no excavation will be required to remove the main valve and the movable parts of the drain valve.

3.10 *Main Valve Remains Closed After Accident.* The barrel and operating mechanism shall be so designed that in case of accident, damage or breaking of the hydrant above or near the grade level, the main valve will remain closed reasonably tight against leakage or flooding.

3.11 *Operating Mechanism.* The operating threads of the hydrant shall be designed so as to avoid the working of any iron or steel parts against other iron or steel. Either the operating stem or the operating nut shall be, or both may be, of non-corrodible metal. The operating stem and nuts shall have square, V, or Acme threads which shall be designed with a factor of safety of not less than 5 for all stresses that may occur when a wrench with a 15-inch arm is used on a hydrant subjected to water pressure of 150 pounds per square inch.

3.12 *Stuffing Boxes.* Stuffing boxes shall be made of cast iron or bronze. The width of the packing shall be at least $\frac{1}{4}$ inch, and the depth of the packing space shall be at least four times its width. Glands shall be made of solid bronze, or of cast iron with bronze bushings. If a packing nut is used it shall be of bronze or other non-corrodible metal, and shall be properly secured so that it will not revolve with the operating stem. Gland bolts or studs may be

iron, steel or non-corrodible metal. If of non-corrodible metal, their diameter shall be not less than $\frac{5}{8}$ inch; or, if of other metal, not less than $\frac{1}{2}$ inch. The nuts shall be made of bronze or other suitable non-corrodible metal.

3.13 *Drain Valve Mechanism.* A positive operating non-corrodible drain valve or valves shall be provided to drain the hydrant properly by opening as soon as the main valve is closed, and to close tightly when the main valve is opened. The seat of the drain valve shall be made of bronze or other non-corrodible material and shall be fastened securely in the hydrant.

3.14 *Drain or Waste Outlet.* An outlet for drainage shall be provided in the base or barrel, or between the base and barrel of the hydrant. It shall be made of bronze or non-corrodible metal, or bushed therewith completely from the valve to the outside. When stipulated by the user, the opening shall be tapped for receiving a threaded pipe to carry the drainage away from the hydrant.

3.15 *Hydrant Top.* The hydrant top or bonnet shall be free-draining, and of a type that will maintain the operating mechanism in readiness to use under freezing condition. It shall be so designed to make tampering difficult, and be provided with convenient means to afford lubrication to insure ease of operation, and the prevention of wear and corrosion.

3.16 *Operating and Cap Nuts.* The operating nut and the cap nuts on the hose and pumper nozzles shall conform to those in service in the system where the hydrant is to be installed. Unless otherwise required, nuts shall be of pentagonal shape. The pentagon shall measure $1\frac{1}{2}$ inches from point to flat at the base of the nut and $1\frac{7}{16}$ inches at the top. Faces shall be tapered uniformly, and the height of the nut shall be not less than 1 inch. The point to flat dimension is to be measured to the theoretical point where the faces would intersect were there no rounding off of the corner. Wrenches for these nuts shall have no taper in the openings, so as to be readily reversible.

3.17 *Direction of Opening.* The direction of rotation of the operating nut to open the hydrant should conform to the practice in the water system where the hydrant is to be installed. Unless otherwise ordered by the purchaser, the hydrant shall be opened by turning the operating nut to the left, counter clockwise. An arrow and the word "OPEN" shall be cast in relief to be clearly visible, on the top of the hydrant to designate the direction of opening.

3.18 *Interchangeability.* Similar parts of hydrants of the same model, size, and make shall be interchangeable with each other without any special fitting.

3.19 *Machined Surfaces.* All machined surfaces shall be so designated by the manufacturer on any drawings requested by the user for approval. Such surface shall be suitably finished for the service and fitting intended.

3.20 *Water Hammer.* The operating mechanism, particularly the pitch of the thread of the operating stem, shall be so designed ~~that~~ when the operating nut is turned at a proper rate to shut off the flow of water, the static pressure plus water hammer shall not exceed twice the static—if the static pressure averages 60 pounds per square inch or greater. If the static pressure averages less than 60 pounds per square inch the pressure shall not be raised more than 60 pounds above static.

3.21 *Friction Losses.* With a hydrant 5 feet in length discharging 250 gallons per minute through each 2½-inch hose outlet, the friction loss shall not exceed the following:

FLOW	PRESSURE LOSS
gallons per minute	*pounds per square inch*
250	1
500	2
750	3
1000	4

Section 4—Materials of Construction

4.01 *Parts of Cast Iron.* The parts where cast iron may be used are the foot-piece or elbow, the barrel or standpipe, the frost jacket if used, the bonnet, the gates of gate-type hydrants, the nozzle caps and small miscellaneous parts where the use of cast iron will conform to good practice.

4.02 *Cast Iron.* All cast-iron parts shall be made of a superior quality of iron. Cast iron shall conform to Specification A-126-30 for Class B Gray Iron Castings for Valves of the American Society for Testing Materials, or the latest revision thereof. All castings shall be clean and sound, without defects of any kind. No plugging, welding or repairing of defects will be permitted.

4.03 *Wrought Iron.* Wrought iron, where used, shall conform to Specification A-41-36 or A-84-36 of the American Society for Testing Materials, or the latest revision thereof.

4.04 *Steel.* Steel, where used, shall conform to Specifications A-31-36 or A-107-36 or A-18-30 of the American Society for Testing Materials or the latest revision thereof.

4.05 *Parts of Non-Corrodible Metal.* The parts where bronze or other non-corrodible metal shall be used are:—the hose and pumper nozzles; the valve seat or seat ring; the drain valve mechanism; and other parts elsewhere herein so specified or where the use of non-corrodible metal will conform to good practice.

4.06 *Characteristics of Non-Corrodible Metal.* All parts made of a non-corrodible alloy such as brass or bronze shall be made from a metal having a tensile strength of not less than 30,000 pounds per square inch, a yield point of not less than 14,000 pounds per square inch, and an elongation of not less than fifteen per cent (15 per cent) in two inches.

4.07 *Facing of Main Valve Against Seats.* The main valve of the hydrant shall be faced with a suitable yielding material such as rubber, leather, balata or composition where it bears on metal seats. The material shall be clamped so that the valve will not leak at the stem. The bottom stem threads may be protected by a suitable cap nut.

4.08 *Bolts and Nuts.* All bolts and nuts shall conform to Specification B18.2-1933 of the American Standards Association, or the latest revision thereof. They shall be of first class workmanship and the metal shall conform in physical characteristics to the provisions of these specifications for wrought iron or wrought steel or bronze, respectively. Unless otherwise specified by the purchaser, special treatments such as Parkerizing to minimize corrosion will not be applied.

Section 5—Details of Construction

5.01 *Test Bars.* At least one test bar shall be made and tested by the manufacturer from each heat of metal used, in accordance with the Specifications of the American Society for Testing Materials pertaining thereto.

5.02 *Shop Inspection.* Representatives (such as the engineer or inspecting engineer) of the purchaser shall be given at all times ready access to places where material for the purchaser is being produced, and they shall have authority to pass on quality and workmanship, and to disapprove and reject work and materials which in their judgment do not conform to the spirit and intent of these specifications.

5.03 *Shop Tests.* Hydrants, for a working pressure of 150 pounds per square inch or less, shall be subjected, after assembly, to two shop tests under a hydraulic pressure of 300 pounds per square inch. One test shall be made with the whole interior of the hydrant under

pressure; and another with the main valve closed and the foot-piece under pressure from the inlet side. Unsatisfactory conditions due to leakage or other imperfections found in either test shall be corrected before the hydrant is accepted.

Section 6—Marking

6.01 *Marking.* All hydrants shall have permanent markings, identifying the manufacturer by name, initials or abbreviations in common usage, designating the size of the main valve opening and the year of manufacture. Markings shall be so placed as to be readily discernible and legible after hydrants have been installed.

Section 7—Painting and Coating

7.01 *Coating.* All iron parts of the hydrant, inside and outside, shall be thoroughly cleaned and thereafter, unless otherwise stipulated, all surfaces except the exterior portion above the ground line shall be coated, painted with or dipped in an asphalt or bituminous base paint or coating. If these parts are painted they shall be covered with two coats, the first being allowed to dry thoroughly before the second is applied. If these parts are dipped they shall be preheated and the coating material shall be heated to a temperature employed in the coating of cast-iron pipe.

7.02 *Shop Coating Above Ground Line.* The outside of the hydrant above the finished ground line shall be thoroughly cleaned and thereafter painted in the shop with two coats of paint of a durable and weatherproof composition which shall produce a surface to which later coats with a linseed oil or other approved base will readily adhere. The color or colors to be used shall be as specified by the purchaser.

Supplementary Information

In purchasing hydrants under these specifications ("A. W. W. A.—N. E. W. W. A.—1940") it will be necessary to make specific statements listing the requirements with relation to the following details:

	Refer to Paragraphs
Size of main valve opening	2.02
Depth of trench (length of hydrant)	2.03
Diameter of inlet connection	3.04
Style of inlet connection—bell or flange	3.04
Number and size of hose nozzles	2.03 and 3.06
If A.S.A. (National) Standard Thread, so specify	3.06
If not A.S.A. (National) Standard Thread, specify the following details:	
Outside diameter of male thread finished.	
Diameter of root of male thread.	
Number of threads per inch.	
Pattern of thread.	
Cut off——of an inch at top of thread.	
Leave —— of an inch in bottom of valley.	
Number and size of pumper nozzles	2.03 and 3.06
If A.S.A. (National) Standard Thread, so specify	3.06
If not A.S.A. (National) Standard Thread, specify the following details:	
Outside diameter of male thread finished.	
Diameter of root of male thread.	
Number of threads per inch.	
Pattern of thread.	
Cut off —— of an inch at top of thread.	
Leave —— of an inch in bottom of valley.	
Harnessing lugs, if required	3.05
Nozzle cap washers, if required	3.08
Shape and size of operating nut	3.16
Direction to turn to open	3.17
Corrosion resistance treatment, if required	4.08
Color above ground	7.02

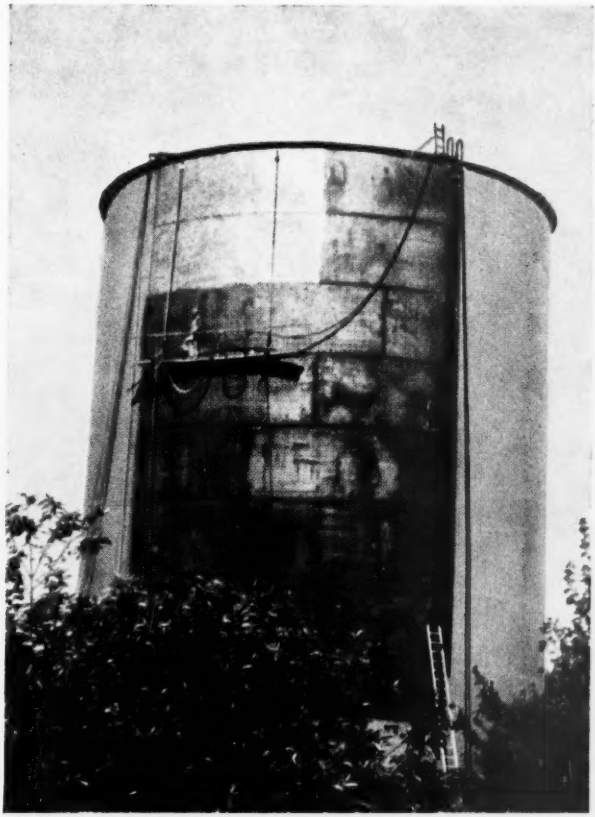
Characteristics of the National Standard Fire-Hose Coupling Screw Thread

Basic dimensions of National Standard hose coupling screw threads are shown in the following tabulation. The complete document (B26-1925) may be obtained at a price of 25¢ per copy from the American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y.

1	Nominal inside diameter of hose coupling	$2\frac{1}{2}$	3	$3\frac{1}{2}$	$4\frac{1}{2}$
2	Number of threads per inch	$7\frac{1}{2}$	6	6	4
3	Total length of threaded part of coupling and hydrant nipple, external thread	1	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$
4	Distance from face of nipple to start of second turn	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{7}{16}$
5	Depth of coupling swivel to washer seat	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$1\frac{3}{16}$
6	Distance from face of coupling swivel to start of second turn	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$
7	Depth of thread of coupling swivel	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{15}{16}$

All dimensions given in inches.

Outer ends of external and internal thread should be terminated by the "Higbee Cut" on *full thread* to avoid crossing and mutilation of thread.



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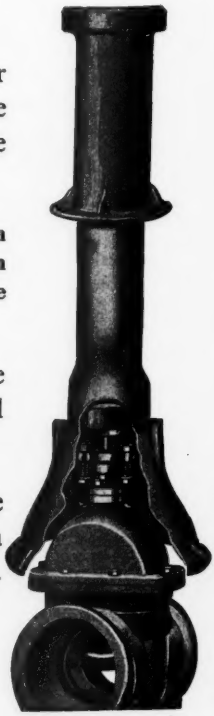

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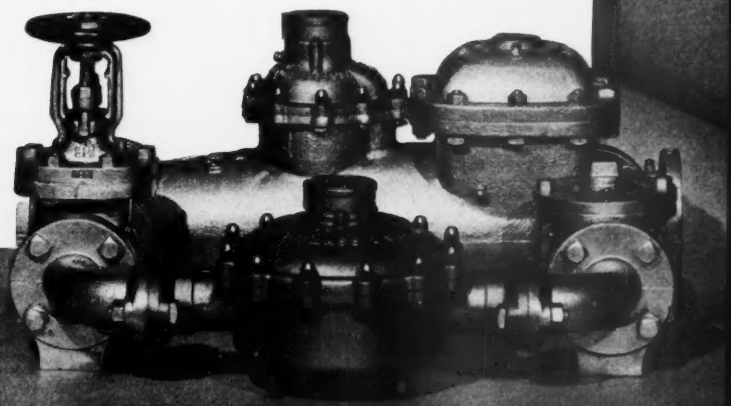

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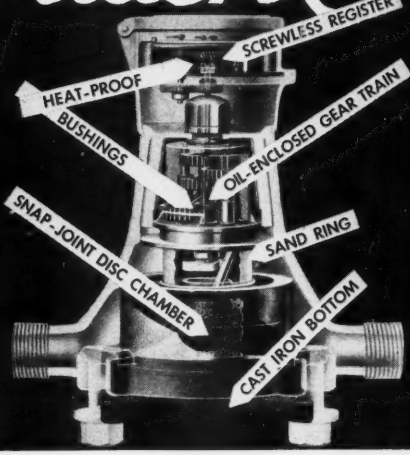

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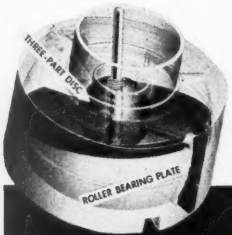

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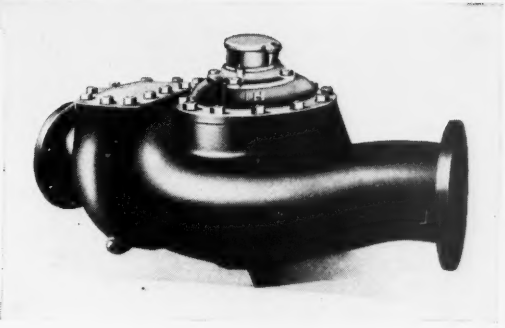

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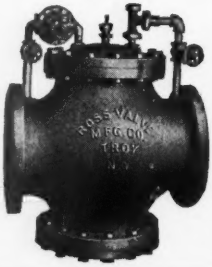

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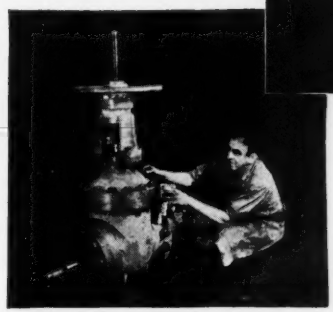

TWO VIEWS of individual valve tests at the Darling plant. Painstaking care in production details, plus thorough inspection, means that Darling customers receive full benefit of the excellence of Darling design.

. . . and a viewpoint. We believe in doing all things well. Every Darling Valve is tested and inspected under its rated test pressure. Darling prohibits "lot testing."

Into all Darling Valves go many years of experience, and the specialized skill of artisans who take pride in their job.

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GATE VALVES AND FIRE HYDRANTS

DARLING VALVE & MANUFACTURING CO.
WILLIAMSPORT, PA.

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TIGHT JOINTS

REGARDLESS OF PIPE SIZE OR SOIL CONDITION

UNDER all conditions of service cast iron water mains can be laid with assurance of permanently "bottle-tight" joints if HYDRO-TITE is used as the jointing compound.

No matter how large or small the pipe nor how tough the going may be, HYDRO-TITE will prove the easiest and most economical to use.

HYDRO-TITE has a record of more than a quarter century without a failure anywhere.

A Symbol of Quality

A Dependable Self-Caulking Joint Compound

HYDRO-TITE

HYDRAULIC DEVELOPMENT CORPORATION

Main Sales Office: 50 Church Street, New York, N. Y.
General Offices and Works: West Medford Station, Boston, Mass.

UNDERGROUND LEAKAGE . . .

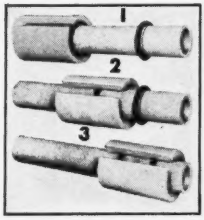
and how it can be minimized with this simple, "packaged" joint

GENERALLY recognized by waterworks men as a serious problem, joint leakage not only results in a direct waste of water but, by washing away supporting soil, frequently causes pipe to fracture under traffic and earth loads.

Much of this trouble is caused by the fact that the ordinary rigid joint, even though perfectly made by skilled workmen, may open up when subjected to vibration or settlement after the line is in service.

One Solution . . .

Such potential dangers are minimized with a *flexible* joint. And that is the principle upon which the Simplex Coupling, employed in assembling Transite Pipe, was designed. Consisting of a Transite sleeve and 2 rubber rings, it forms a tight joint that stays tight. Its flexibility compensates for vibration and for vertical, longitudinal and lateral movements to which the pipe may be subjected underground.



Simplex Coupling Assembly
(1) At start of operation
(2) Sleeve pulled over one ring
(3) Final position, sleeve centered over joint

Simplicity—the best insurance against defective joints

The dependability of the Simplex Coupling is due primarily to these distinctive features:

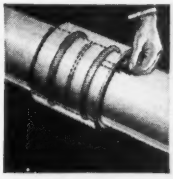
1. It is actually a pre-fabricated, "*packaged*" joint. The ends of the pipe and the inside of the coupling are machined to exact dimensions. The rubber rings are precision-made. Joints are assembled cold—no pouring, caulking or heating equipment is needed. A simple hydraulic coupling puller, loaned without charge, is the only tool required for assembly.

2. The effectiveness of the joint does not depend on the individual skill or training of the workmen. So simple is the operation that perfect Simplex joints can be made quickly and economically even by completely unskilled crews.

The Simplex Coupling is assembled with a hydraulic puller. The collar engages the edge of the Transite sleeve; the jack fits over the open end of the pipe.

Made of Permanent Materials

The Transite sleeve, like the pipe itself, is made of asbestos and cement and has the same high degree of resistance to all forms of corrosion. The rings, made of the highest quality rubber, are carefully cured and specially compounded with anti-oxidants and properly graded non-hygroscopic fillers to assure permanence in water service.



With Simplex Couplings, tightness of the joint can be determined from the outside as soon as the pipe is laid. A thin steel blade, slipped under the lip of the sleeve, checks the position of the rubber ring. If the position is right, the joint is tight.

. . . and a word about Transite Pipe

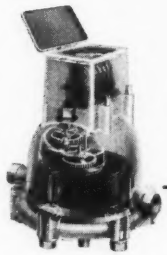
Transite Pipe has helped bring many waterworks problems under control—tuberculation, soil corrosion and electrolysis, and the toll they exact in excessive operating and maintenance costs, to mention but a few. Full details on Transite Pipe and Simplex Couplings are in Catalog TR-11A. We'll be glad to send you a copy. Johns-Manville, 22 East 40th Street, New York, N. Y.

NOTE TO ENGINEERS: The "J-M Pipe Installation Manual," a 76-page book that outlines in detail effective methods of installing water lines, contains much more data on the Simplex Coupling than was possible to include above. A copy will be sent you on request.

Johns-Manville TRANSITE PIPE

For efficient, economical water and sewer lines

Buy the meter that will cost you least



Even when EMPIRE METERS sold for more than they do today, they were still the cheapest meters you could buy. When you figure the cost of removing, repairing and replacing a stopped meter . . . and when you figure the amount of revenue lost on meters which register less and less as time goes on . . . it becomes apparent that *over-all cost* should be your chief consideration when buying meters. EMPIRE METERS *cost least in the long run.*

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Empire METERS

STOUGHTON, MASS., SELECTS "Century" ASBESTOS-CEMENT PIPE FOR ECONOMICAL, TUBERCULATION-PROOF LINES . . . .

1 "Century" Asbestos-Cement Pipe gives Stoughton, Mass., low-cost, tuberculation-proof lines. Stoughton was the first New England town to protect its lines permanently against tuberculation by using "Century" Pipe.

THE pressure lines recently laid by the town of Stoughton, Mass., had to be proof against tuberculation—a condition common in New England. "Century" Asbestos-Cement Pipe was selected, not only because it is permanently non-tuberculating and corrosion-proof, but because it is economical in first cost and minimizes maintenance.

"Century" Pipe is strong, trouble-free and enduring. It is light in weight for easy handling and rapid laying. Its "Century" Flexible Couplings not only permit curving a line without elbows or bends, but they are lastingly leak-proof as well.

Write Keasbey & Mattison, asbestos specialists since 1873, for free, illustrated catalogue, "Mains without Maintenance." Address Dept. 1017.

2 "Century" Pipe is so light in weight that it is readily handled with a simple block and fall. In all except the largest sizes it is often lowered into a trench with the help of ropes alone.

3 Mr. B. L. Winslow, Town Manager of Stoughton, is seen with W. E. Haywood, K&M Field Engineer, right. Mr. Winslow says—"Tuberculation-proof lines were essential. 'Century' Pipe gave us this feature, with low maintenance cost in addition."

KEASBEY & MATTISON
COMPANY, AMBLER, PENNSYLVANIA

K&M best in asbestos

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The FIRE CHIEF likes Safetop *Convenience* - -

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The HYDRANT MAINTENANCE MAN likes Safetop *Reliability* - -

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No danger of flooding if accidentally broken, no interruption of water service or street excavation, and speedy return to service if breakage repairs or extension for change of street grade are necessary.

The TRUCK CHAUFFEUR likes Safetop *Safety* - -

No likelihood of serious personal injuries in case of unavoidable collision against the hydrant due to slippery streets or traffic accidents. No fire hydrant is worth a human life.

The Kennedy Valve Mfg. Co., Elmira, N. Y.

KENNEDY SAFETOP
REG. U.S. PAT. OFF.
FIRE HYDRANT

EDDY

Valves and Hydrants

Distinctive Features of the EDDY Valves

ONLY three parts are moved by the Stem—the ball and the two gates. Each gate is hung from one of the trunnions on the ball. A convex surface at the base of each trunnion fits a concave surface on the back of the gate. This allows the gates to adjust themselves properly to their seats. . . . The gates, being free to revolve on the trunnions, do not always seat in the same position. Gates are center bearing and adjustable. They are forced to their seats with equal pressure at all points. There are two hooks on the ball on sizes 4-inch and larger, which loosely engage with the gates.

Distinctive Features of Our New Swivel Top Hydrants

THIS new hydrant has all the advantages of the popular EDDY fire hydrant, plus several additional features. . . . Nozzles are in a short flanged section of the standpipe, which may be unbolted and turned to different positions. . . . Should the standpipe be broken, only the casting below the swivel head need be replaced. . . . To raise the hydrant to conform to a new grading, simply insert a flanged extension piece below the swivelhead. No digging. To add a steamer nozzle at any time, it is only necessary to replace the swivel head with one having a steamer nozzle.

Besides valves and hydrants to meet the most exacting demands of waterworks service, the complete EDDY Line includes: valves for sewage disposal works; valves for steam, gas and oil; check valves, foot valves, plug valves, shear gates, indicator posts, etc. EDDY valves are made in three classes: Iron Body Bronze Mounted, All Bronze, and All Iron Valves.

Eddy Valve Co.

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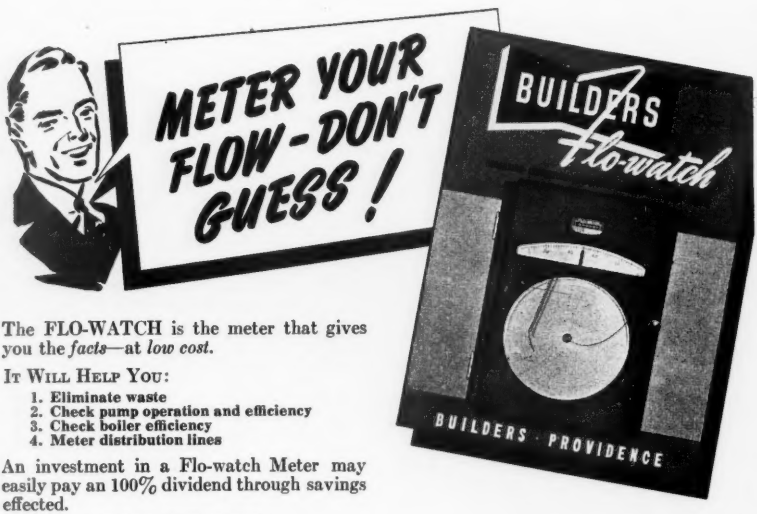

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IT WILL HELP YOU:

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An investment in a Flo-watch Meter may easily pay an 100% dividend through savings effected.

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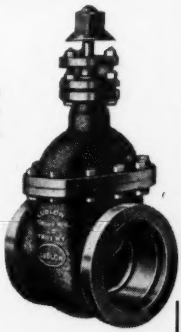
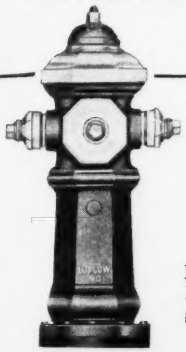


New construction — increased industrial activity — mean that your water supply and fire protection system may be forced to carry a greater load than ever before. Will it stand the strain?

Ludlow's basic construction principles — standards of the industry — are your insurance against faulty operation and costly time-consuming delays. Be prepared against failure and fire — be sure your specifications read "Ludlow."



Ludlow List 90 Fire Hydrant with slide-gate-wedge principle

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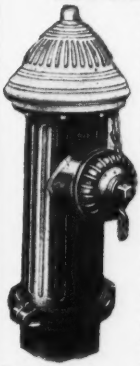
East Orange, New Jersey



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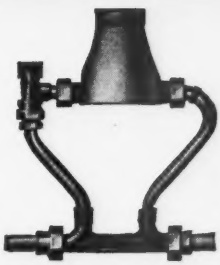
Machines for inserting valves under pressure, and for making large right angle connections to mains under pressure, and for inserting house service connections under pressure.
Also makers of—
Pipe Cutting Machines, each size being adjustable for use on three different sizes of pipe.
High-grade water works supplies, such as Hydrants, Valves, Meters, Corporation Cocks, etc.
We also make a new type of hydrant which has a breakable joint at the ground line which when struck with an impediment will break at a specified point and only a coupling has to be used to repair the hydrant, which will be back in service in twenty (20) minutes.

"HYDRANT WITH BREAKABLE COUPLING"

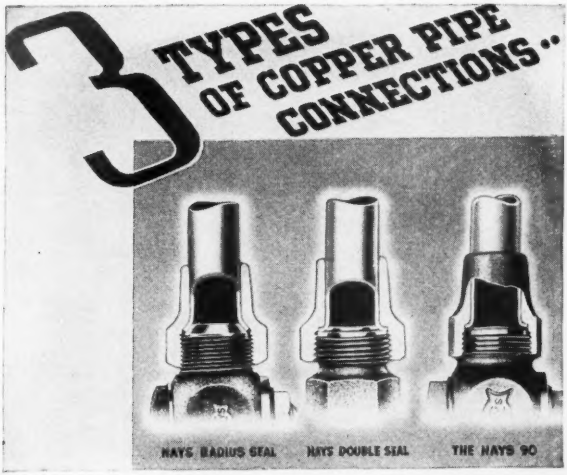
SMITH
WATER WORKS SPECIALTIES & SUPPLIES
THE A.P.SMITH MFG.CO. East Orange,N.J

The Coppersetter
A COMPLETE METER MOUNTING



The COPPERSETTER is a simple, convenient and durable fitting for installing water meters in horizontal service lines. It is all brass and copper, made in several heights and can be provided with an inverted ground-key angle valve at the meter inlet. Write for more information about the COPPERSETTER.

The Ford Meter Box Co.
WABASH, INDIANA



Whatever tapping method or type of corporation cock your city uses, Hays can take off with copper pipe to the curb or to the meter. Hundreds of water works departments have found Hays permanent copper services readily adaptable to their needs at little or no extra cost over short life methods.

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SINCE 1869

HAYS

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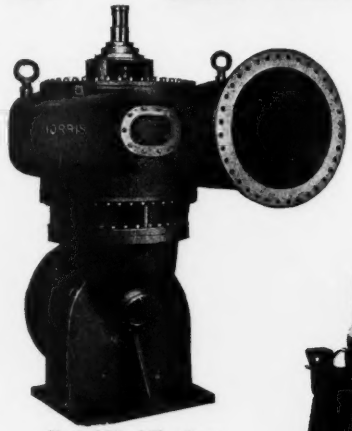
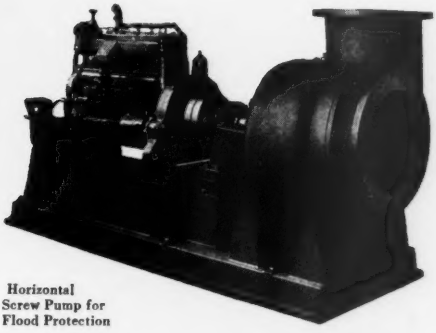
CENTRIFUGAL PUMPS



Vertical Mixed Flow Pump
for Sewage

for Sewage and Drainage



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Morris Centrifugal Sewage and Drainage Pumps, like the Morris designs for water supply, are notable for their high efficiency; and in addition, have special features which assure non-clogging and trouble-free service. These designs are built both vertical and horizontal, and for standard or low-speed motors and other methods of drive. Full information on request.

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PUMPS FOR METROPOLITAN DISTRICT COMMISSION

Photograph shows the two pumps described in the preceding issue, ready to be lowered in the shaft.

We shall be pleased to supply information on centrifugal pumps for Water Works and Sewage Plants for all capacity and head conditions.

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TRENTON, NEW JERSEY

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"WHEN your nose starts toward a glass of water, and the result isn't pleasant," says Bill Bryan, Superintendent, Water Purification Plant, Tarboro, N. C., "try BREAK-POINT Chlorination!"

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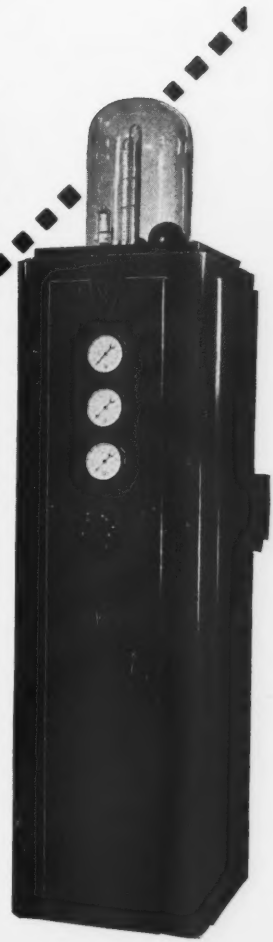
BREAK-POINT Chlorination possesses this outstanding advantage — you can accurately determine beforehand—by reliable laboratory tests in your own plant—what BREAK-POINT can do for you. There is no cost or obligation. Just call your nearest W & T representative or write



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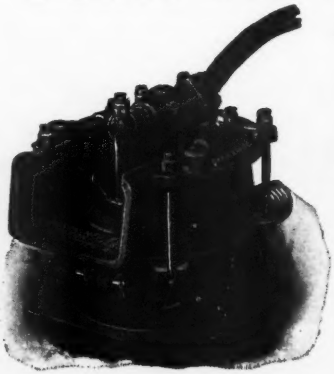

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NO EFFECT ON WATER QUALITY

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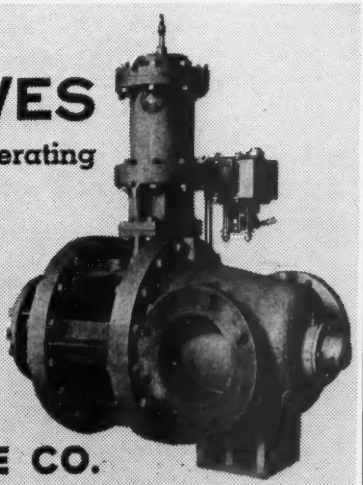

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Pipe Laying Jobs NEED NOT BE DELAYED

waiting for that initial leakage to stop. Trenches need not remain open, with resulting hazards to traffic . When you use Tegul-MINERALEAD, those joints seal almost at once. You can backfill and clear up the street right away . Tegul-MINERALEAD is the sulphur-base, ingot form compound that

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3—Can't change composition in transit.
4—Needs no skilled labor, caulking or deep bell holes.
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6—Saves you labor, time and money.

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for Jointing Bell & Spigot Pipe

DONALDSON IRON CO.

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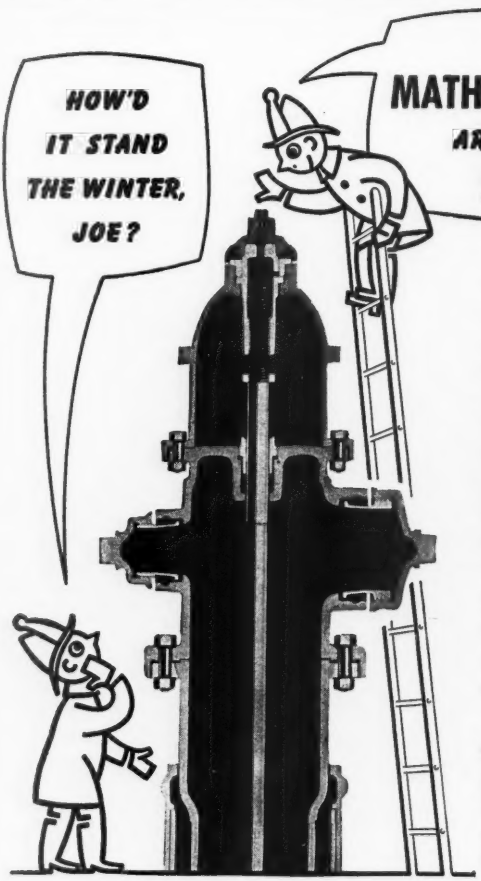

Over 70 years of being always ready through any weather has proved that Mathews Hydrants really are frostproof. It's shown them to be the standard of winter safety. Be sure your hydrants have these essential features:

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The Mathews operating thread is dry — sealed against both external and internal water.

•

Frost-heaved ground cannot crack or lift a Mathews Hydrant. The ground grips only its loose protection case.

•

Water can't stand in a properly set Mathews. Its one-piece drain valve is positive and automatic.

•

Specify Mathews Hydrants. Write for prices, diagrams, or any facts you want.

MATHEWS HYDRANTS

Made by R. D. WOOD COMPANY

Manufacturers of Sand Spun Pipe (centrifugally cast in sand molds) and R. D. Wood heavy-duty gate valves for water works

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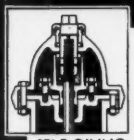
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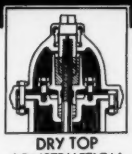
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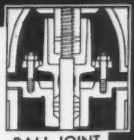
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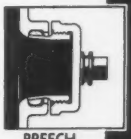
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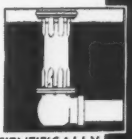
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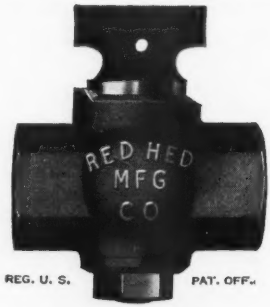

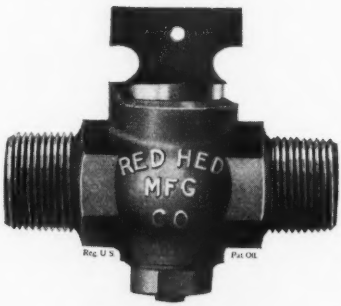

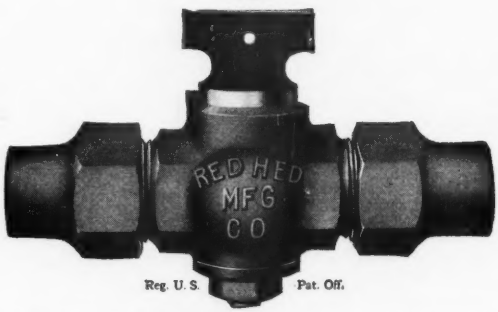

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